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TECHNOLOGY ACCEPTANCE, ACCEPTABILITY AND APPROPRIATION IN PROFESSIONAL BUREAUCRACIES: THE CASE OF RFID FOR IMPROVING MOBILE ASSETS MANAGEMENT IN HOSPITALS

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Cette thèse s'intitule :

TECHNOLOGY ACCEPTANCE, ACCEPTABILITY AND APPROPRIATION IN PROFESSIONAL BUREAUCRACIES: THE CASE OF RFID FOR IMPROVING MOBILE ASSETS MANAGEMENT IN HOSPITALS

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DEDICATION

This thesis is dedicated to my precious daughter Gabriella who has given me the best gift of my life. Her smiles have been the inspiration to complete this journey.

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This dissertation is the culmination of my research journey. This achievement could not have been accomplished without the support and collaboration of many who I would like to acknowledge.

First and foremost, I would like to express my deepest gratitude to the late Professor Louis A. Lefebvre who was an endless source of wisdom, encouragement, motivation, and inspiration. I am also very grateful to Professor Élisabeth Lefebvre who has unconditionally provided me with guidance, support, encouragement, and advice for all the phases of this research.

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I cannot for confidentiality reasons disclose the name of the participants in this research study, but I thank you individually. We all have shared a memorable experience. I have thoroughly enjoyed and appreciated the friendship of my fellow graduate students from the ePoly center, in particular, Ygal Bendavid, Yassine El-Ghazali, Jenny Moreno, and Alejandro Romero.

I would also like to thank my parents for their love, support, and encouragement. Finally, I would like to dedicate this dissertation to my beloved daughter and husband, Gabriella and Eli Bendavid, whose endless love, boundless support, and relentless motivation were my greatest inspiration to achieve this dream. Thanks Gabriella and Eli for all you have given me. I could not have done it without you!

RÉSUMÉ

Les hôpitaux, même ceux de petite taille, peuvent gérer sur une base quotidienne plusieurs milliers d'actifs fixes et mobiles. Les actifs mobiles sont très diversifiés et incluent des pompes à infusion, du matériel chirurgical, des électrocardiogrammes, des machines portables à rayons X, des défibrillateurs, etc. Ces actifs circulent en permanence entre les différents services et les divers départements. Pratiquement tous les patients dépendent d'un ou plusieurs actifs mobiles lors de leur hospitalisation. Ces actifs sont également indispensables à la prestation des soins de santé et le personnel clinique consacre une partie importante de leur temps pour chercher ces actifs lorsque requis. L'incapacité de retrouver ces actifs en cas d'urgence peut mettre la vie des patients en danger.

La technologie RFID (Radio Frequency Identification) a le potentiel de retracer et d'effectuer le suivi, et ce, de façon unique et transparente, les actifs mobiles et, par conséquent, d'en améliorer leur gestion dans les hôpitaux. Comparé à d'autres secteurs d'activité, le secteur de la santé adopte RFID à un rythme beaucoup plus lent, ce qui se traduit par un nombre limité d'études empiriques portant sur l'implantation de RFID dans ce secteur. Cette thèse se propose donc de contribuer à ce vide empirique par une analyse en profondeur d'une implantation réelle de RFID. Cette implantation vise à améliorer la gestion d'un type d'actifs mobiles, nommément les pompes à infusion dans un hôpital.

Les données empiriques ont été recueillies pendant une période de 25 mois, de la phase de préfaisabilité jusqu'à la phase de post-implantation. Huit organisations (incluant l'hôpital qui est le principal site d'observation) et 35 participants ont été impliqués. Les résultats de la recherche peuvent être résumés comme suit.

À la question, pourquoi RFID est implanté? La réduction des inefficacités existantes liées à la gestion des actifs mobiles en est la principale raison. De plus, la familiarité avec les technologies de l'information au sein de l'hôpital, la compatibilité de l'infrastructure existante (l'hôpital est presque 100% Wi-Fi) et l'expérience des partenaires technologiques sont des facteurs positifs reliés à l'implantation RFID.

Comment l'implantation RFID est-elle effectuée? Les résultats montrent que le processus d'implantation est fortement itératif : les participants reviennent en effet sur les phases précédentes et modifient les décisions approuvées antérieurement. L'amélioration continue des services de soins est sans aucun doute la préoccupation principale exprimée par tous les participants de l'hôpital. Toutefois, les attentes et les exigences diffèrent entre les différents groupes de participants. Les résultats démontrent un clivage entre les points de vue de l'administration et ceux du côté clinique. Des divergences sont notées entre les infirmières et les médecins, et, entre les techniciens de l'hôpital (responsables des TIC, ingénieurs biomédicaux, et spécialistes de la maintenance) et les administrateurs. Les enjeux les plus importants ne sont pas technologiques, mais sont principalement organisationnels, ce qui semble découler de la présence de points de vue divergents.

Est-ce que la RFID améliore la gestion des actifs mobiles? Les résultats suggèrent que les avantages identifiés et évalués lors l'implantation de RFID appartiennent aux catégories suivantes: amélioration de la visibilité des actifs, augmentation de l'efficacité opérationnelle, réduction de certains coûts et émergence de processus intelligents. Ce dernier point apparait comme particulièrement important. Les processus intelligents misent principalement sur les capacités d'auto-identification et de sensibilité au contexte (*context-awareness*) de RFID, sur le changement automatique de statuts, et sur la mise à jour automatique des applications d'hôpital (par exemple, WMS). Les résultats démontrent également que les processus intelligents améliorent la planification et la prise de décision.

Est-ce que les caractéristiques intrinsèques des organisations dans lesquelles la technologie RFID est envisagée posent des contraintes à son implantation? Les hôpitaux, qualifiés de bureaucraties professionnelles, constituent un ensemble unique de contraintes dont on doit tenir compte lors d'une implantation RFID. En particulier, l'inertie, la complexité et la rigidité organisationnelles ne sont pas favorables à des changements à grande échelle dans l'hôpital et affectent la façon dont RFID est implanté. En outre, l'existence d'une structure à double pouvoir et les pièges liés à une culture forte (*culture entrapment*) ont un impact profond sur l'importance des avantages découlant de RFID.

Est-ce que l'acceptation de la technologie, son acceptabilité et son appropriation représentent des concepts clés pour comprendre l'implantation de la RFID ? Ces trois concepts ont été explorés lors de cette recherche et ont conduit à deux observations principales. Tout d'abord, on peut affirmer que si la technologie est acceptée, acceptable et appropriée, elle est utilisée, de façon partielle ou plus large. Par extension, l'acceptation, l'acceptabilité et l'appropriation pourraient être importantes non seulement pour expliquer l'ampleur de l'utilisation d'une technologie (utilisation partielle par rapport à la pleine utilisation), mais aussi pour expliquer les raisons pour lesquelles une technologie a été initialement adoptée, puis ensuite rejetée. Deuxièmement, les résultats empiriques ne confirment pas un ordre chronologique entre ces trois concepts. Par exemple, l'appropriation ne suit pas l'acceptation, même au début de l'implantation. Au contraire, l'acceptation, l'acceptabilité et l'appropriation coexistent à tout moment pendant le processus d'implantation. Cependant, l'ordre chronologique joue quand même un rôle puisque les niveaux d'acceptation, l'acceptabilité et l'appropriation varient au fil du temps. En outre, ces trois concepts sont sensibles à la fois à la technologie (dans ce cas, RFID) et au contexte dans lequel cette technologie est utilisée (l'hôpital), qui continuent de leur côté à changer au fil du temps.

La thèse se termine en examinant les limites de la recherche, en proposant quelques pistes de recherche. Les contributions de cette thèse peuvent être pertinentes pour les chercheurs, les décideurs du secteur de la santé, les administrateurs d'hôpitaux, et les spécialistes et consultants en TI.

ABSTRACT

Hospitals, even small ones, handle on a daily basis several thousands of mobile and fixed assets. Mobile assets are very diverse, ranging from infusion pumps, surgical equipment, electrocardiograms, portable x-ray machines, defibrillators to wheelchairs and rotate constantly between different medical wards. Since virtually every patient depends on one or more mobile assets during his or her hospital stay, they are also indispensable in healthcare delivery. Clinical staff spends a significant share of their working time searching for these essential, but commonly misplaced assets. Locating mobile assets is not only a time consuming activity, but the inability to find them when needed is remarkably costly, and possibly life threatening.

RFID (Radio Frequency Identification) holds the potential to uniquely and seamlessly track and trace mobile assets and, thus, to improve mobile asset management in hospitals. Compared to other sectors, healthcare organizations adopt RFID at a much slower pace and only a limited number of empirical studies address RFID adoption and implementation in the context of healthcare. This thesis intends to contribute the research arena by analysing a real-life RFID implementation in order improve the management activities of one type of mobile assets, namely infusion pumps in hospital settings.

The research focuses on a real-life RFID implementation in one European hospital. Empirical data was collected for a 25 month period from the pre-feasibility stage to post-implementation stage from eight organizations (including the hospital as the main observation site) and from thirty-five participants. Research results can be summarized as follows.

To the question **why RFID is implemented?** The most straightforward answer is to reduce the existing inefficiencies related to mobile assets management. Technological preparedness and readiness drive RFID implementation: This includes familiarity with IT innovations within the hospital, compatibility with existing IT infrastructure (the hospital is almost 100% Wi-Fi enabled), and experience of technological partners with RFID implementation in various sectors.

How RFID implementation is carried out? The answer seems to be through a highly iterative five stage process where participants revisited and modified previously agreed steps. The continuous improvement of care services was without a doubt the superseding concern expressed

by all participants from the hospital. However, expectations and requirements differ among different groups of participants. The empirical evidence demonstrates not only a cleavage between the administrative and clinical perspectives, but also within the clinical perspective. Divergences run deep within each perspective (for instance, nurses vs. doctors) and between the technologists in the hospital (ICT managers, biomedical engineers, and maintenance specialists) and the administrators. The most significant issues related to such implementation are not technological but are mainly organizational, as they seem to arise from the presence of diverging perspectives.

Does RFID really improve mobile assets management? Results suggest that the benefits identified and evaluated during the real life RFID implementation belong to the following broad categories: improving assets visibility, promoting operational efficiency, reducing costs and facilitating the emergence of intelligent processes. Intelligent processes are mainly derived from the RFID capabilities for auto-identification and context-awareness, process automatic status change, and automatic update in hospital's enterprise applications (i.e. WMS). Results further demonstrate that intelligent processes improve planning and decision-making.

Do the intrinsic characteristics of organizations play a role in RFID implementation? The very characteristics of hospitals, qualified as complex professional bureaucracies, constitute a unique set of constraints to be taken into account for RFID implementation. In particular, organizational inertia, complexity and inflexibility are not conductive to hospital-wide changes and affect how RFID is implemented. Moreover, the existence of a dual power structure and a tendency to culture entrapment may have a profound impact on the importance of the benefits derived from RFID.

Do technology acceptance, acceptability and appropriation represent key concepts that should be considered to understand the implementation of RFID? These three concepts were explored in the research. This leads to two main observations. First, it could be stated that if technology is accepted, acceptable and appropriated, then it is fully used. By extension, acceptance, acceptability and appropriation could be significant not only in explaining the extent of use of a technology (partial use vs. full use), but also the reasons why a technology was initially adopted and then discarded. Second, empirical results reject the presence of a chronological order between the three concepts. For instance, appropriation does not follow acceptance, even initially. Rather, acceptance, acceptability and appropriation coexist at any time during the implementation process. However, chronology still matters since the levels of acceptance, acceptability and appropriation vary over time. Furthermore, these three concepts are sensitive to both the technology (in this case RFID) and to the context where it is use (the hospital), which are also changing over time.

The thesis examines research limitations, proposes some research avenues and outlines contributions that may be relevant for researchers, healthcare policy makers, hospital administrators, IT specialists and IT consultants.

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LIST OF ACRONYMS AND ABREVIATIONS

AACP	American Association of Colleges of Pharmacy
AIDC	Automatic Identification Data Capture
AMA	American Medical Association
AmI	Ambient Intelligence
ANA	American Nurses Association's
API	Application Programming Interface
BPR	Business Process Redesign
CEO	Chief Executive Officer
CMA	Canadian Medical Association
CPOE	Computerized Physician Order Entry
EPCGlobal	Electronic Product Code Global
EMR	Electronic Medical Record
EPCs	Event-driven Process Chains
ERP	Enterprise Resource Planning
FDA	Food and Drugs Administration
GDP	Gross Domestic Product
GPS	Global Positioning System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HCOs	Healthcare Organizations
HF	High Frequency
HIT	Health Information Technology
ICT	Information and communication technology

IEEE	Institute of Electrical and Electronics Engineers
IR	Infra-Red
IS	Information System
ISO	International Standards Organization
IT	Information Technology
KPI	Key Performance Indicator
LF	Low Frequency
MES	Manufacturing Execution Systems
MMS	Material Management System
NHS	National Health Service
NPfIT	National Program for IT
NPO	Non-Profit Organization
OECD	Organisation for Economic Co-operation and Development
PDA	Personal Digital Assistant
POC	Proof of Concept
RF	Radio Frequency
RFID	Radio Frequency Identification Technology
RO	Read Only
ROI	Return on Investment
RTLS	Real Time Location Systems
SARS	Severe Acute Respiratory Syndrome
SME	Small and Medium Enterprise
TAM	Technology Acceptance Model
TAM2	Technology Acceptance Model2

TAR	Theory of Reasoned Action
TPB	Theory of Planned Behavior
UHF	Ultra-High Frequency
US DOD	US Department of Defense
UTAUT	Unified Theory of Acceptance and Use of Technology
UWB	Ultra Wide Band
WORM	Write Once/Read Many Times

INTRODUCTION

Healthcare constitutes undeniably a pivotal social and economic element of our modern society. It is also a complex sector « in transition » (Eisler et al., 2006) as it faces siftings in population demographics, speedy technology transformations, shortage of medical professionals, and increasing cost pressures. Across the globe, nations are dedicating astronomical budgets to support the care delivery process (Reyes et al., 2012). In order to deliver services at the point-of-care, healthcare organizations need to rely on a multitude of resources such as information (electronic and paper based), medical supplies such as medicines, specialized medical staff and support staff, clinical and non-clinical assets and a complex infrastructure. In particular, mobile medical devices such as infusion pumps, pulse oximeters, portable X-ray units, cardiac monitors, ventilators, and surgical equipment need to be accessible at the right time, at the right place and in the right condition (for instance, disinfected) to diagnose, monitor or treat the patient. However, these valuable and critical devices are not always available when medical professionals need them to deliver care. Mobile medical devices are known for being often misplaced, hoarded or lost within hospital facilities; thus delaying care, lowering the satisfaction of the patient experience at the hospital, and potentially affecting the quality of care. The inefficient management of critical medical assets is a growing issue contributing to the "wastebaskets" of healthcare (PWC, 2010) and affects negatively hospital's operational expenditures budgets.

RFID (Radio Frequency Identification) has the potential to play a significant role for improving hospital core processes at the clinical and non-clinical levels (Yao et al., 2012) and, more specifically, in reducing existing inefficiencies related to mobile assets management. Even though RFID has been around for several decades, it is still considered as an emergent and disruptive technology worth of further study (Fosso Wamba, 2012; So, 2012; Bendavid and Cassivi, 2010).

The majority of studies on RFID adoption and implementation have been conducted in the manufacturing and retailing sectors and in supply chain settings (Yao et al., 2012; Chong and Chan, 2012). Compared to other sectors, healthcare organizations adopt RFID at a much slower pace (Yao et al., 2012) and only a limited number of empirical studies address RFID adoption and implementation in the context of healthcare (Reyes et al., 2012). This thesis intends to contribute the research arena by analysing a real-life RFID implementation in order improve mobile asset management activities in hospital settings. Specially, this thesis intends to identify and evaluate the areas of opportunities for improvement within mobile asset activities in relation to infusion pumps. The thesis will investigate the potential factors promoting or blocking the implementation of RFID within clinical settings and conduct an in-depth assessment of RFID potential benefits for improving mobile asset management.

The dissertation is organized into seven chapters. Chapter 1 presents the main characteristics of hospitals considered as professional bureaucracies that may influence the implementation of ICTs (information and communication technologies) in general and of RFID in particular. Chapter 2 offers a discussion on ICTs adoption and implementation, introduces the concepts of technology acceptance, acceptability and appropriation, presents an overview of RFID technology and its applications in healthcare, and, examines existing implementation models. Chapter 3 proposes a conceptual framework based on the two previous chapters and specifies the main characteristics of the research design. Chapter 4, 5 and 6 correspond to the three thesis articles. The last chapter (chapter 7) discusses the overall results, outlines the limitations and highlights the significance of the contributions at the methodological, theoretical and practical levels. The thesis concludes with future research avenues.

CHAPITRE 1 THEORETICAL BACKGROUND AND RESEARCH CONTEXT

This chapter presents a targeted review of the literature on professional bureaucracies in general (sections 1.1, 1.2 and 1.3) before examining the characteristics of hospitals that represent a specific subclass of professional bureaucracies (section 1.4). This chapter thus offers a broad background of the organizational context in which this research is grounded. Specific attention was placed on issues raised by innovation and change in professional bureaucracies.

1.1 Bureaucracies and fundamental principles

Organization theory is deeply rooted in history. Earlier significant contributions known as the *Scientific School of Thought* can be traced to prominent authors such as Fredirick W. Taylor (1911), Henry Fayol (1917), Michel Crozier (1964) and Max Weber (1978). The study of organizations was then dominated by rationality (Baum and Rowley, 2005). However, Crozier made compelling arguments to include the human relations approach into organization theory and proposes in his book "The Bureaucratic Phenomenon" a model to understand the French bureaucratic system using the concepts of vicious circles and dysfunctions.

Weber introduced the term bureaucracy that he considered as the ideal and efficient form of organizational structure (Weber, 1946a). The author emphasized the importance of knowledge and stated that the "bureaucratic administration means fundamentally domination through knowledge" (Weber, 1978, p. 225). Weber offered considerable insights into the formal conceptualization of organizations by suggesting that a bureaucracy can be characterized by the following principles:

1) A formal hierarchical structure which implies chains of commands where authority comes from the level above as well as centralized planning and decision-making;
2) Formalized rules that are executed consistently across the organization and standard operating procedures that allow increased efficiency and predictability;
3) A high level of specialization based on a sphere of competences, and, functional expertise which allows efficiency since everyone does what he or she knows best;

4) A clear mission of the organization that can be either "up-focused" (for instance, by serving the stockholders or improving the health of a community), "in-focused" (for instance, by generating high profits), or both (up-focussed and in-focussed);
5) A purposely-impersonal treatment of both employees (which can mean protection from favouritism or arbitrary dismissal) and customers (which implies a uniformed level of services).

The above principles still appear to be very in place today in most bureaucracies.

1.1.1 Disadvantages and advantages of bureaucracies

Weber was quite realistic about the future of bureaucracies as he viewed them as a potential threat to individuals: increased rationalization and inflexible formalized rules may entrap them in what he called “iron cages” and lead them into “a polar night of icy darkness” (Weber, 1946b). His visions are relatively close to the feelings of most people today who are dealing with or working in bureaucracies: frustrations, red-tape and inflexibility are probably the most symptomatic expressions used to describe these organizations. Scholars were also quite critical of Weber’s bureaucracy and have stressed several overriding issues such as a limited scope for human resources, a rigidity that is not suitable for organizational change in dynamic and volatile environments, and a negative impact on knowledge sharing since centralization and formalization hamper inter-group information exchange and collaboration (Kim and Lee, 2006; Hall and Tolbert, 2004; Willem and Buelens, 2007; Yang and Maxwell, 2011)

Some authors, far less numerous than the Weber’s detractors, stress the advantages of bureaucracies. Stability and impartibility arise from the logic and rationality of bureaucracies (Peters, 2001; Stazyk and Goerdel, 2011). Furthermore, bureaucracies seem to better address complexity than other organizational structures (Vasconcelos and Ramirez, 2011). The new reforms concerning the public sector entail several negative effects (Pollit and Bouckaert, 2004) that may even point to the “rediscovery” of bureaucracy (Olsen, 2006).

1.2 Beyond bureaucracies: other organizational structures

Mintzberg states that “Every organized human activity – from the making of pots to the placing of a man on the moon – gives rise to two fundamental and opposing requirements: the division of labor into various tasks to be performed and the coordination of these tasks to accomplish the activity" (Mintzberg, 1979, p.2). The organizational structure refers to the different ways in which an organization breaks down labour into tasks and how attains the coordination of such tasks (Mintzberg, 1979). This section seeks to gain an in-depth understanding of the different organizational structures.

Previous work from Henry Mintzberg represents the theoretical core of professional bureaucracies, which are considered as one of the five organizational structures (also termed configurations) that he has initially proposed. In order to derive configurations, Mintzberg relies on three elements: 1) the key parts of an organization, 2) the coordination mechanisms, and 3) the types of decentralization (Figure 1-1)

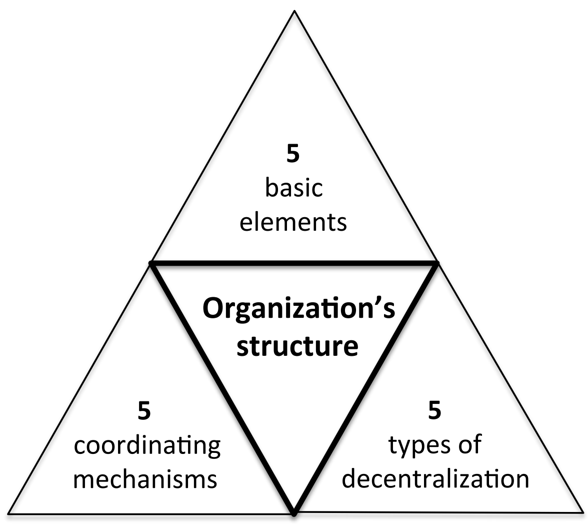

Figure 1-1 Elements delineating the structural configuration of an organization (Mintzberg, 1980)

The key parts of an organization

Any organization consists of five key parts (Figure 1-1), namely, the strategic apex, the operating core, the middle line, the technostructure, and the support staff (Mintzberg, 1980; 1983).

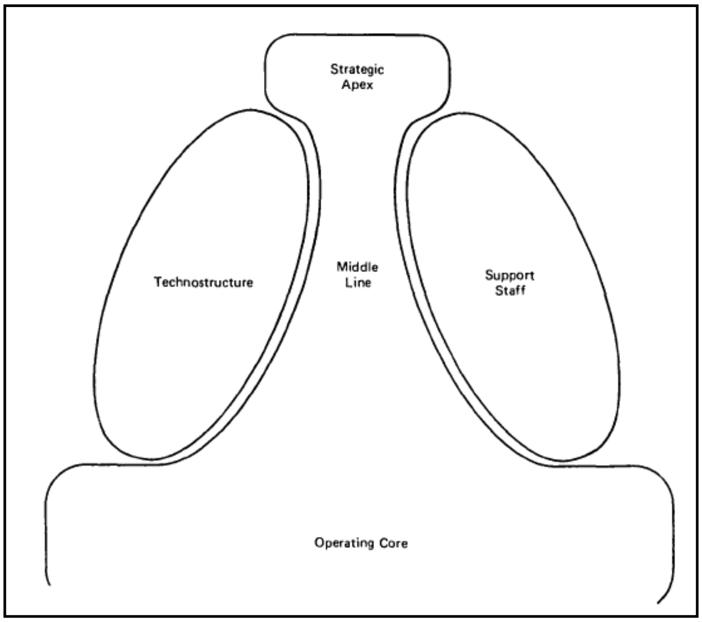

Figure 1-2 Five basic parts of an organization (Mintzberg, 1980)

1) *The strategic apex* (top part of Figure 1-2) regroups organization's top management and their personal staff that oversees the entire organization, conceive visions and elaborate strategic goals. It regroups, among others the board of directors, the CEO (chief executive officer), and directors.
2) *The operating core* (bottom part of Figure 1-2) is composed of employees who perform all necessary tasks directly related to the production of products or services. For instance, in a manufacturing company, it includes blue workers such as machine operators and assemblers and white collars such as the purchasers or the sales personnel.
3) *The middle line* involves middle and lower level managers and supervisors who administer the work done by operational staff and other managers. They serve as a link between the strategic apex and the operating core. They support the strategic apex as they take over responsibilities delegated by the organization's top management. These managers are part of the chain of authority (Mintzberg, 1983) since their hierarchical authority will decrease according to their proximity to the operating core.
4) *The technostructure* (left hand-side in Figure 1-2) comprises a group of people, the analysts, who are responsible for defining the techniques and tools necessary to execute work of operational groups in order to attain a standardization of work. They employ analytic

techniques to advise, design and somewhat run the necessary systems in order to coordinate, plan and control the "line operations". This group includes planners, accountants, production schedulers, etc.

5) *The support staff* (right hand-side in Figure 1-2) comprises a group of people responsible for indirect services to the rest of the organization. This group could include staff working in the payroll office, the cafeteria, mailroom, etc.

Human resources are therefore omnipresent in all five parts of an organization, but the relative importance of one part over the other ones allows the characterization of a specific organizational configuration. An alternative way to represent the five key parts of an organization (Lunenburg, 2012) is closer to the usual pyramidal representation of management (operations, control and strategy).

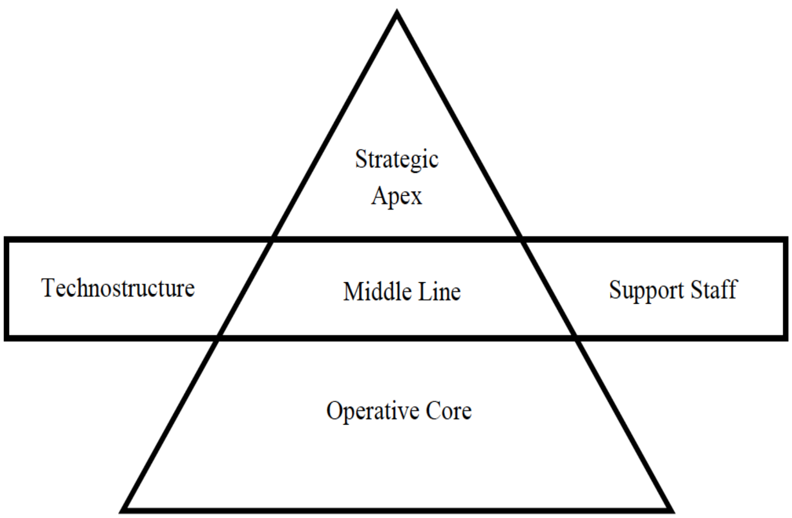

Figure 1-3 The five basic parts of an organization: an alternative representation (Lunenburg, 2012)

Coordinating mechanisms

The concept of coordination finds its roots from Thompson's work. Coordination efforts correspond to ''the kinds of cooperation of different people required to get the job done effectively" (Thompson, 1967, p. 10). He further suggested that *standardization and mutual adjustment as well as planning are key* mechanisms needed to coordinate work activities in order to respond to three different patterns of dependencies, namely pooled, sequential or reciprocal interdependences (Thompson, 1967, p. 54-55).

According to Mintzberg (1980), the coordinating mechanisms represent the second element to differentiate structural configurations. *Direct supervision* refers to a coordination mechanism in which one individual is responsible for coordinating other people's work and therefore provides precise orders and directives to others in order to ensure work achievement.

Standardization of work processes is achieved by the imposition of standards, usually provided by the technostructure, in order to guide the way work has to be done. *Standardization of outputs* happens when the results of different work are specified, for instance, with standard performance measures, usually generated by the technostructure. *Standardization of skills* represents the internalization by individuals of standard skills and knowledge through training, usually before they begin to do the work while the *standardization of norms* refers to beliefs and expected behaviors that are shared across the organization. Finally, *mutual adjustment* refers to the coordination mechanism in which individuals coordinate their own work through informal communication.

Melin and Axelsson (2005) evaluated Mintzberg's five coordinating mechanism and concluded that they don't cover appropriately essential aspects of organizational coordination. Particularly, authors pointed some limitations in regards to dynamic issues such as i) coordination history, ii) external influence, iii) emergent processes, iv) concurrency and variation, and v) communication. Nevertheless, the authors agreed that such coordinating mechanisms are more significant when use to comprehend formal division of labour, stable organizational structures and roles, as well as planned coordination.

Types of decentralization

The third and last element that allows delineating different organizational configurations is derived for the concept of decentralization. This concept refers to "the extent to which power over decision making in the organization is dispersed among its members" (Mintzberg, 1980, 1983).

The different types of decentralization correspond to:

1) Vertical and horizontal decentralization that refers to the extent to which power flows, largely parallel, all the way down the line of authority and then out at the bottom to the operator of the operating core. Typically, most of the power rests in the operating core.
2) Vertical and horizontal centralization where formal and informal power is mainly located in the strategic apex.
3) Limited horizontal decentralization where formal power remains at the strategic apex; however, the strategic apex shares some informal power with the analysts of the technostructure. The latter has a major role in standardizing work.
4) Limited vertical decentralization where formal power is delegated to managers of market-based units, so that they can make necessary decision regarding their assigned units.
5) Selective decentralization where decision-making power is dispersed broadly in the organization to various organizational units or "work constellations" at various levels.

As depicted in **Erreur ! Source du renvoi introuvable.**, organizational structures could be classified into five main configurations, each being characterized by one predominant part of the organization, one particular coordinating mechanism, and one type of decentralization (Mintzberg, 1980). The simple structure is usually found in young and entrepreneurial firms whereas the machine bureaucracy is characterized by many hierarchical layers and numerous formal procedures. The professional bureaucracy, characterized by professional expertise, by standardization of skills and by vertical and horizontal decentralization, is the focus of the thesis and is discussed in the next section. The divisionalized form is mostly present in multinationals where central authority is limited, but where business units may be rather autonomous. The adhocracy (a term first proposed by Toffler in 1970) or innovative configuration, in opposition to a bureaucracy, refers a fluid and highly organic structure with low levels of standardization and formalization (Mintzberg, 1983). Work is organized by projects and is typically conducted by flexible teams. For Waterman, adhocracy is “any form of organization that cuts across normal bureaucratic lines to capture opportunities, solve problems, and get results” (Waterman, Jr., 1990). For Mintzberg, it is the organization of the future (Mintzberg, 1979). Each of these five configurations presented in **Erreur ! Source du renvoi introuvable.** affects the people who work in the organization in different manners and all organizational structures need to support the strategic goals set by the organization (Nelson and Quick, 2011, p. 525).

Beside the key parts of organizations, the coordination mechanisms and the types of decentralization, structures are also affected by contingency factors such as age, size, technical system, environment, and power (Minztberg, 1980). Organizational structures therefore evolve over time. To the five initial organizational configurations, Mintzberg has added a sixth one, namely the missionary organization (Mintzberg, 1979, 1980) that is strongly influenced by the needs of their environment.

Table 1-1 Characteristics of organization's structure (Mintzberg, 1980)

Organization's structure	Basic part of the organization	Coordinating mechanism	Type of decentralization
Simple structure	Strategic apex	Direct supervision	Vertical and horizontal centralization
Machine bureaucracy	Technostructure	Standardization of work processes	Limited horizontal decentralization
Professional bureaucracy	Operating core	Standardization of skills	Vertical and horizontal decentralization
Divisionalized form	Middle line	Standardization of outputs	Limited vertical decentralization
Adhocracy	Support staff	Mutual adjustment	Selective decentralization

Lemieux (1998) asserts that Mintzberg's organizational configurations present various exceptional advantages including:

1) The fact that it surpasses the theoretical limitations of models that theorize organizational structure exclusively in terms of hierarchical lines of authority. Mintzberg acknowledges that organizations' transactional communication does not always flow according to the administrative structure.
2) It provides needed flexibility to integrate the distinctive cultural contextual factors into his proposed basic organizational configurations. No all organizations have the same structure since they operate in different environments.

3) The organizational structure is not “structural” but “functional” given that Mintzberg focuses his interest in how organizations work or function instead of looking at what organizations do.

1.3 Professional bureaucracies

1.3.1 The prevailing characteristics of professional bureaucracies

Professional bureaucracies are the focal point of this research. They are characterized as being complex organizational structures in which the operating core is the key part of the organization, the standardization of skills represents the chief coordinating mechanism and decision making relies on vertical and horizontal decentralization as previously illustrated in Table 1-1 (Mintzberg, 1980).

In professional bureaucracies, the operating core is represented by a set of highly trained professionals who possess a high-level skills and knowledge, which is gained through several years of training and indoctrination (Wetzel, 2001). Given their specialized expertise and skills, they work independently from top management (strategic apex) and middle line managers, and, in some occasions, even from their own colleagues. However, they are very close to the organization’s clients who are the recipients of the outputs (products and services) they produce (Wetzel, 2001). Hospitals, law firms, universities, as well as governmental agencies are some examples of professional bureaucracy organizations.

Professional bureaucracies achieve control and coordination of their activities through the standardization of the skills and knowledge of their professionals (Mintzberg, 1980; Nelson and Quick, 2011). Professional work is greatly specialized, but slightly formalized, while training is extensive. Typically, the size of the top management team and of the technostructure group tends to be relatively small. The members of the support staff are numerous in order to deliver the activities needed to support the work of professionals at the operating core (Lunenburg, 2012; Nelson and Quick 2011).

Professional bureaucracies concede a great deal of power to their specialized professionals, emphasizing the authority that comes with the “nature” of their profession or the “power of expertise” (Surgeon, 1990). “With control passes allegiance; professionals tend to identify more with their profession than with the organization wherein they happen to practice it" (Surgeon, 1990). Consequently, professionals frequently "act as a community within a community with distinctive and integrated occupational cultures" (Surgeon, 1990). Nevertheless, the professional benefits from belonging to an organization are shared across the organization and this is the case for facilities, sophisticated equipment, training, etc. (Mintzberg, 1992).

Since authority comes from the power of professionals' expertise and, since the nature of their work entails considerable levels of complexity, decision-making is decentralized. Moreover, control in professional bureaucracies is achieved primarily through "horizontal" rather than "hierarchical" processes (Ham and Dickinson, 2008). Consequently, the administration body concedes a great deal of power to the operating core (Mintzberg, 1980; Surgeon, 1990; Pettersson and Andersson, 2012) in comparison to other type of organizational structures such as machine bureaucracies where the power remains at the strategic apex (Wetzel, 2001). In other words, the authority is of "hierarchical nature" in machine bureaucracy while it is one of a professional nature in professional bureaucracy (Surgeon, 1990). However, the administration does have some power over the support staff. Consequently, two parallel hierarchies usually emerge in professional bureaucracies: "one democratic and bottom-up for the professionals, and a second machine bureaucratic and top-down for the support staff" (Mintzberg, 1983).

In the same line of thought, Surgeon (1990) suggests that organizations with a prevailing power of expertise and autonomy of operating professionals could be referred as "collegial" and display "inverse pyramids" or "inverted power structure" since i) professionals are placed at the top of the management pyramid and administrators are located at the bottom to assist professionals (Figure 1-4), and ii) professionals are more influential with respect to decision making than the staff in formal positions of authority (Surgeon, 1990; Ham and Dickinson, 2008). Consequently, when top management and administrators desire to integrate new guidelines, policies or practices in professional bureaucracies, they need to negotiate with the operating core group rather than impose directives (Ham and Dickinson, 2008).

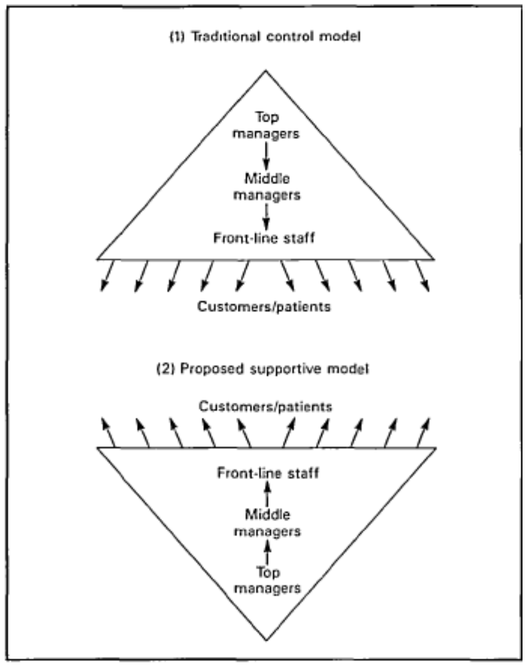

Figure 1-4 The inverted power structure in professional bureaucracies (Surgeon, 1990)

Finally, the literature suggests that the presence of professionals may affect the control of the organization since the organizational structure is moulded by their needs (Badrick and Preston 2001). In professional bureaucracies, management implies more coordinating the experts rather than monitoring them. Indeed, the professionals detain a wide control over their own work. Consequently, managers should not forget that their control relates only to the goals of the organization, not to the professional delivery (Fogel, 1989).

Table 1-2 Prevalent characteristics of professional bureaucracies

Prevalent characteristics	Description	Source
Key element	Key component of these organizations is the operating core	Mintzberg in Unger et al. (2000)
Standardization of skills	Professionals put to use their acquired skills and knowledge in order to generate standardized products and services.	Wetzel (2001); Fogel (1989)
	The objective is the standardization of professional's skills rather than standardization of the outputs	Mintzberg in Unger et al. (2000)
	A standard set of skills is shared by the professionals	Fogel (1989)
Power of expertise	Operational staff detain a high level of control by virtue of their training and professional knowledge	Ham and Dickinson (2008)
	Emphasizes authority of a professional nature	Wetzel (2001)
Professional autonomy	High degree of autonomy for working units	Mintzberg in Unger et al. (2000)
Authority	Professionals have more control over their own work as well as detain collective control over administrative decisions	Wetzel (2001)
	Professional authority supersedes administrative (bureaucratic) authority	Fogel (1989)
	Professionals play key leadership roles	Ham and Dickinson (2008)
	Hierarchical directives issued by top management have limited impact, and may be resisted by front line staff	Ham and Dickinson (2008)
Control	Control of the core processes is detained by highly trained and autonomous professionals rather than administrators	Zell (2003)

1.3.2 Innovation and change in professional bureaucracies

Professional bureaucracies are more inclined to be stable than to embrace change; consequently, they tend to be inflexible and conservative and innovations are difficult to implement (Fogel, 1989). Indeed, the literature concurs that the bureaucratic control mechanisms characterizing such organizations hinder both organizational change an innovation (Damanpour, 1996); thus, when change arises, "it is slow and painful" (Fogel, 1989). Furthermore, the professionals play an influential role (Ham and Dickinson, 2008) and are the driving force inhibiting or promoting change; thus, diffusion of change happens through the process of change in the professionals themselves (Zell, 2003). The latter is rather difficult to achieve, especially if the experts believe that the proposed change is not directly related to their own area of expertise and intervention.

The adoption and diffusion of innovations often entail many frustrations from both professionals and administrators in large complex organizations such as professional bureaucracies (Plesk and Wilson, 2001; Jones, 2007). Resistance to change is a significant and sometimes underestimated roadblock to organizational change, particularly in professional bureaucracies. Failure to address and overcome its implications makes the change process "slow, messy, chaotic, and unsuccessful" (Zell, 2003). Battling resistance to change appears to be a lost cause. Instead, it is more valuable to evaluate and understand "how individuals and groups work through their resistance to change" (Zell, 2003). In particular, professionals, with high levels of autonomy and power that come from their expertise, need to be involved in the innovation and change process and must agree to it before change can take place and be implemented (Plesk and Wilson, 2001). These professionals may perceive the implementation of change initiatives as a treated to their authority, status and institutionalized values. For instance, Ilie (2005) reveals that in hospitals settings medical professionals may see a new information technology as a "competing artefact" posing a threat to their status and values and, thus, prompting their resistance to such change.

1.4 Hospitals as professional bureaucracies

Organizations in the healthcare sector, particularly hospitals, operate under a very unique environment making them a highly interesting setting for research. Hospitals have been considered as "extraordinarily complicated organizations" that are "notoriously difficult to manage" (Glouberman and Mintzberg, 2001, p58). Hospitals are categorized as "professional bureaucracies" since work carried out by the operating core is very complex, and, it is performed and can only be performed by professionals (Glouberman and Mintzberg, 2001, p348; Mintzberg 1983 in Surgeon, 1990; Fogel, 1989). In this organizations, the operating core include professionals such as physicians, residents, fellows, registered nurses, nursing assistants, pharmacists, respiratory therapist, psychologists, among others, who detain highly specialized skills and knowledge that were acquired through an enduring and lengthy training process (Glouberman and Mintzberg, 2001, p348; Mintzberg, 1983 in Surgeon, 1990; Fogel, 1989). Complex work can only be effectively executed when it comes under the control of the professional who is trained to do such work. As Mintzberg mentions, "it is not the hospital that delivers the baby, this is done by the individual professional" (Minztberg, 1983).

1.4.1 The authority, autonomy, independence, professional status and expertise of medical professionals

In a hospital setting, the professionals provide healthcare services directly to the customers -i.e. the patients. Indeed, physicians have been given substantial authority to relate directly to patients (Wetzel, 2001). Their work remains highly unstandardized as healthcare services tend to be extremely complex and consequently too sophisticated for standardization. Thus, the work of medical professionals cannot be adequately supervised by middle line managers or by analysts from the technostructure (Fogel, 1989). In particular, physicians and medical specialists have a great level of autonomy and hence work without any technical supervision or evaluation. This level of autonomy is also intrinsic to their own individual values as their university studies reinforce the tendency to operate independently (Fogel, 1989). Furthermore, physicians and other medical experts' values are based on professional differentiation (Fiol and O'Connor, 2004). Finally, these professionals are identified as the "healing class" and have "a validated power to heal" (Anderson and McDaniel, 2000 in Ilie, 2005; Blumenthal, 2002 in Ilie, 2005). As it is expected in a professional bureaucracy context, healthcare professionals tend to defend their autonomy against the influence of the central apex and capitalize on the very weakness of the technostructure. To sum up, the medical profession within the hospital is basically characterized by autonomy, independence, professional status and expertise (Blumenthal, 2002 in Ilie, 2005). This last statement holds to a large extent, but we have to acknowledge that some strict guidelines arise from their respective associations (for instance, the American Medical

Association (AMA), the Canadian Medical Association (CMA), the American Nurses Association's (ANA), American Association of Colleges of Pharmacy (AACP). However, these associations are external.

To illustrate the large degree of freedom given to physicians to practice their profession, Ham and Dickinson (2008) state the following based on the case of the NHS (National Health Service) in the U.K.: "At the inception of the NHS, the Government made clear that its intention was to provide a framework within which the health professions could provide treatment and care for patients according to their *own independent professional judgement of the patients' needs*. This independence has continued to be a central feature of the organisation and management of health services. Thus hospital consultants have *clinical autonomy* and are *fully responsible* for the treatment they prescribe for their patients. They are required to act within broad limits of acceptable medical practice and within policy for the use of resources, but they are not held accountable to NHS authorities for their clinical judgements."

1.4.2 The complexity of healthcare related work

In their book "Social Organization of Medical Work", Strauss and his co-authors (1997) examine the complexity of healthcare related work. The authors raise the fact that healthcare work entails activities with human beings, posing constraints and characteristics not found in other sectors. Indeed, "work with and on human beings has characteristics not present when the material worked on is inanimate" (Strauss et al., 1997). Wetzel (2001) complements this last comment by stressing the fact that "human material reacts, is able to participate, influences the results, is part of the divisions of labour and increases especially in case of illness significantly the contingencies of work".

1.4.3 The dual power structure, work coordination and leadership

According to theorists such as Strauss et al. (1963 in Germov, J., 2005), hospitals are characterized by the present of a dual power structure of bureaucratic rules and professionalism. Generally, hospitals organize work into three separate branches that correspond to medical, nursing, and administration staff (Mintzberg, 1983 in Bradrick and Preston, 2001). In the context of professional bureaucracies, the control and the coordination of activities are mainly achieved through horizontal rather than hierarchical processes and professionals tend to rely on collegial influences to secure work coordination. Indeed, professional bureaucracies are formed of collections of 'microsystems', comprising multi-professional teams in charge of carrying out daily work (Batalden et al, 2003 in Ham and Dickinson, 2008). In hospitals, this microsystem refers to "the place where patients, families, and care teams meet". It is also considered as "frontline care" where support staff, processes, technology, recurring patterns of information and behaviour, and, results meet to deliver care (Dartmouth Medicine, 2006). If clinical microsystems are seen as essential (Denis et al., 2001 in Ham and Dickinson, 2008), their leadership is dispersed. Consequently, clinical professionals are taking the leadership roles, either informally or formally, at different levels of the organization.

1.4.4 Information and knowledge intensive organizations

Healthcare is recognized as the "most information-intensive" industry in the modern economy (Stead and Lin, 2009; Austin and Boxerman, 2003; Banks et al, 2007; Burdis et al., 1999; Bates, 2002). Medical professionals rely on multiple sources of information, clinical and non-clinical, in order to diagnose and treat their patients. Consequently, it is necessary that hospitals rely more and more on IT in order to "acquire, manage, analyze, and disseminate health care information and knowledge" (Stead and Lin, 2009). Paradoxically, healthcare organizations (including hospitals) invest in and uses less information and communication technologies than almost any other information-intensive sector of the economy (Bates, 2002; Helms et al., 2009). Consequently, current hospital information technologies are characterized as relatively "primitive" and "unsophisticated" (Bates, 2002; Helms et al., 2009).

Today's market place is considered as a highly challenging, dynamic, and above all, *knowledge-intensive* environment. As results, information and communication technologies (ICT) are essential to any strategy targeting at increasing productivity, lessening costs and improving care delivery (Tsiknakis and Kouroubali, 2009). Hospitals have to respond to the characteristics of the external environment while being themselves very knowledge-intensive organizations. There is no doubt that hospitals do correspond to the definition of knowledge-intensive organizations: They are indeed characterized by capital intensity, broad use of knowledge, and professionalized workforce (Von Nordenflycht, 2010). In fact, they capitalize on several knowledge areas and are composed of numerous interdependent disciplines (Wahle and Groothuis, 2005). The dominant gravitation towards "superspecialism" by the medical professionals creates a very exclusive knowledge that needs to be "secured, disseminated and utilized" (Wahle and Groothuis, 2005).

1.4.5 Hospitals as cultures of entrapment

Organizational culture promotes shared values, norms and assumptions among the people together and this seems to be rather positive. However, a strong organizational culture can also lead to overlook warning signals and thus affect negatively organizational performance (Weick and Sutcliffe, 2003). Hospitals' organizational culture could "entrap" these organizations into actions they are not able to drop, leading to organizational myopia and recurrent actions that hinder improvements. Weick and Sutcliffe (2003) explain that cultural entrapment is "the process by which people get locked into lines of action, subsequently justify those lines of action, and search for confirmation that they are doing what they should be doing."

In addition to the prevalent characteristics of professional bureaucracies previously presented in Table 1-2, we propose that hospitals display some additional characteristics that reflect their specific context. As follows, Table 1-3 presents details of such additional characteristics.

Table 1-3 Additional prevalent characteristics of professional bureaucracies

Prevalent characteristics	**Details**	**Source**
Professional authority, autonomy, and independence	Emphasize on authority and autonomy as a result of the sophistication of their work	Fogel (1989); Ham and Dickinson (2008); Fiol and O'Connor (2004); Blumenthal (2002 in Ilie, 2005);
	Physicians possess a high level of authority, autonomy and independence by virtue of their professional status as the "healing class".	Anderson and McDaniel (2000 in Ilie, 2005); Fiol and O'Connor (2004)
	Professionals are completely autonomous to work directly with their patients without supervision from hospital administrators.	Fogel (1989)
Complexity	Complexity of work as a result of the nature of the work: work with human beings.	Strauss et al. (1997); Wetzel (2001)
Dual power structure	Power in healthcare settings is both of a bureaucratic and a professional nature with professional objectives overriding bureaucratic ones.	Strauss (1963 in Germov, J., 2005)
	Control and the coordination of activities is attaint through horizontal processes.	Ham and Dickinson (2008)
	Professional bureaucracies are typified by distributed leadership with professionals playing central leadership roles.	Denis et al. (2001 in Ham and Dickinson, 2008)
Information and knowledge intensive organizations	Hospitals are recognized as information and knowledge intensive organizations. Information is a key resource for medical practice.	Stead and Lin (2009); Burdis et al. (1999); Bates (2002); Helms et al. 2009); Wahle and Groothuis (2005).
	Hospitals are organizations that demand an extensive use of knowledge by a super-specialized workforce.	Wahle and Groothuis (2005)
Cultures of entrapment	Hospitals' culture could hinder performance improvement since professional could be "entrapped" with old inefficient practices.	Weick and Sutcliffe (2003)

CHAPITRE 2 SPECIFIC RESEARCH CONTEXT

This chapter attempts to position the thesis in its specific research context. Since RFID represents one specific ICT, past research on the adoption, implementation and diffusion of ICTs may offer valuable insights (section 2.1). The next section (section 2.2) turns to the literature on RFID and gives a brief overview of the technology itself (section 2.2.1), offers a discussion on the most significant determinants of RFID adoption and diffusion (section 2.2.2) and analyses RFID implementation models (2.2.3). Finally, RFID applications in healthcare and hospitals (section 2.2.4) are examined.

2.1 Information and communication technologies

Information and communication technologies (ICTs) play a key role in contemporary organizations across all industrial sectors (Basole, 2006). Although ICTs are constantly evolving and, hence, difficult to define, we will retain here the generic definition of ICTs, which states that ICTs represent "the array of primarily digital technologies designed to collect, organise, store, process and communicate information within and external to an organisation" (Ritchie and Brindley, 2005). Information systems represent a subset of ICTs whereas RFID is viewed as one specific ICT.

In a volatile, dynamic and ever changing modern economy, the adoption, implementation and diffusion of these technological innovations is pivotal for organizations that want to remain competitive (Goswami, 2009). The pervasiveness of ICTs and the ever-escalating reliance on these technologies in everyday life, at both the individual and organizational levels, make the study of these technologies a major research stake, especially in the information systems (Verdegem and De Marez, 2011).

Past research demonstrates that ICTs provide several strategic advantages by enabling organizations to improve their performance while decreasing operational costs (Goswami, 2009; Sanders, 2007; Basole, 2006; Hammer and Mangurian, 1987). However, the literature reports on a significant number of failures (Verdegem and De Marez, 2011; Kerimoglu et al., 2008; Basole, 2006). Unsuccessful ICTs implementations entail significant financial losses and thus have a major impact on the organization's bottom line (Venkatesh and Bala, 2008). One of the most frequently cited reasons for these failures is the fact that too much attention is given to the technical determinants without taking into account the individuals' acceptance (Verdegem and De Marez, 2011). Misalignment between ICTs and the organizational context (Kerimoglua et al., 2008) or the business requirements (Davenport, 1998) is also reported as a main cause of failure.

2.1.1 Adoption and diffusion of ICTs

Since ICTs are technological innovations, the studies on the adoption, implementation and diffusion of these technologies find their roots in the innovation theory literature. Adoption of an innovation refers to "the *acceptance* and continued use of a product, service or idea" (Howard and Moore, 1988) whereas diffusion refers to "the process by which an innovation is communicated through certain channels over time among members of a social system" (Rogers, 1983, p. 5). Further, implementation refers to "the process of gaining targeted organizational member's appropriate and committed use of an innovation" (Klein and Sorra, 1996). Not all individuals or units of a social system will try or adopt an innovation at the same time and some innovations diffuse more rapidly than others (Howard and Moore, 1988).

Various authors concurred that the adoption process has an impact on the successful use of information systems (Grover et al., 1998; Karahanna et al., 1999 in Liao et al., 2009). Rogers (1995) describes the adoption process as "the process through which an individual or other decision making unit passes from first knowledge of an innovation, to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision".

2.1.2 Determinants of the adoption and diffusion of ICTs

Determinants of the adoption and diffusion of ICTs fall into four broad categories, namely technological attributes, users' characteristics, organizational characteristics, and environmental factors (Table 2-1).

Characteristics of the technology

The very characteristics of the technology (also called technological attributes) could promote or impede the intention to adopt a technology (Chwelos et al. 2001; Rogers 1983; Iacovou et al. 1995). ICTs and innovations in general can be characterized by five attributes, which are to some extent empirically interrelated, but conceptually different (Rogers, 1983), namely, relative advantage, compatibility, complexity, trialability and observability (Rogers, 1983). Relative advantage refers to the "degree to which an innovation is perceived as being better than the idea that supersedes" (Rogers, 1983, p. 213) and represents one of the most significant predictors of the rate of adoption of an innovation. Compatibility alludes to the "degree to which an innovation is perceived as consistent with existing values, past experiences, and needs of potential adopters" (Rogers, 1983, p. 223). Various research studies have revealed that the more compatible an innovation is with potential adopters' values, beliefs, experiences and needs, the more likely it will be adopted (Wu, 2012). Complexity (opposite to ease-of-use) refers to the "degree to which an innovation is perceived as relatively difficult to understand and use" (Rogers, 1983, p. 230).

Hence, innovations that are perceived as complex will tend to exhibit a lower rate of adoption. Trialability or the "degree to which an innovation may be experimented with on a limited basis" (Rogers, 1983, p231), acts as a more significant determinant for early adopters than for later adopters. Finally, an innovation that allows observability (i.e. the "degree to which the results from an innovation are visible to others") is more likely to be adopted (Rogers, 1983, p232). Each of these five attributes is perceived differently depending on the individual's innovativeness (Verdegem and De Marez, 2011). Indeed, "it is the receiver's perceptions of the attributes of innovations, not the attributes as classified by experts or change agents, that affect their rate of adoption" (Rogers, 1985). Innovators and early adopters tend to have an enhanced perception of the relative advantage of an innovation and a lower perception of its complexity when compared to late majority adopters (Verdegem and De Marez, 2011; Moore and Benbasat, 1991).

Besides the five technological attributes initially proposed by Rogers, some researchers added results demonstrability, image, visibility and voluntariness (for instance, Moore and Benbasat, 1996) while others pointed out the importance of the perceived benefits (Iacovou et al., 1995; Chwelos et al., 2001). Perceived benefits refer here to the level of recognition of the relative advantage that a given technology can bring to the organization (Iacovou et al., 1995) or to an individual.

Table 2-1 Determinants of the adoption and diffusion of ICTs

Characteristics of the technology	Determinants	References
Technological attributes	-Relative advantage	Rogers (1983), Moore and Benbasat (1996)
	- Compatibility	Rogers (1983), Moore and Benbasat (1996)
	- Complexity	Rogers (1983)
	- Trialability	Rogers (1983), Moore and Benbasat (1996)
	- Observability	Rogers (1983), Moore and Benbasat (1996)
	- Ease of use, image, result demonstrability, and voluntariness	Moore and Benbasat (1996)
	- Perceived benefits	Iacovou et al. (1995), Chwelos et al. (2001)
Individual characteristics	- Personality traits	Verdegem and Dr Marez (2011)
	- Demographic (i.e. gender, age, educational level, occupation, etc)	Liao et al. (2009); Verdegem and Dr Marez (2011)
	- Experience and training	Costello and Moreton (2009)
	- Knowledge of IT	Costello and Moreton (2009)
	- Cultural background	Aggelidis and Chatzoglou (2009)
	- CEO characteristics (i.e. age, education or ICT skills)	Hashim (2007: Souther and Tilley, 2000)
Organizational characteristics	- Organizational size	Rogers (1983), Patterson et al. (2003), Ko et al. (2008)
	- Organizational readiness	Sharma (2007), Asif and Mandviwalla (2005)
	- Supply chain structure and performance, supply chain strategy	Patterson et al. (2003)
	- Organizational culture	Asif and Mandviwalla (2005), Raufflet et al. (2005)
	- Quality of human resources - Available slack resources - Managerial structure - Managerial innovativeness	Wu (2012), Chwelos et al. (2001), Iacovou et al. (1995), Premkumar and Ramamurthy (1995), Grover (1993), Saunders and Clark (1992)
Environmental factors	- Firm's industry - Environmental uncertainty - Normative influences - Access to resources - Government regulations	Chwelos et al. (2001), Tornatzkey and Fleischer (1990), Teo et al. (2003)
	- Dependency, power and trust	Saunders and Clark (1992)
	- External pressures	Iacovou et al. (1995)
	- Use of IT required by major business partners	Bouchard (1993)
	- Competitive pressures	Premkumar and Ramamurthy (1995), Premkumar et al. (1997), Wu (2012), Chang et al. (2008), Grover (1993)
	- Pressures from supply chain members	Patterson et al. (2003)

Individuals' characteristics

ICTs adoption and diffusion research that focuses on the individuals' characteristics is mature (Liao et al., 2009). Among the most studied determinants, personality and demographic variables as well as situational variables that account for differences attributable to circumstances (i.e. experience and training) are most cited. Some studies propose psychological models in order to explicate and foresee users' behaviour toward IS adoption (Davis et al., 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003 in Liao et al, 2009). Moreover, individuals pertaining to the same organization or having the same cultural background could respond differently when facing IT adoption (Aggelidis and Chatzoglou, 2009). When individuals are influential (acting as champions, for instance) or are from the top management, their characteristics represent significant determinants. In smaller firms, CEO characteristics such as age, education or ICT skills (Hashim, 2007: Souther and Tilley, 2000) are found to be predictors of adoption and diffusion.

Organizational characteristics

Other studies focus on organizational characteristics. In fact, previous research has demonstrated that organizations can react differently to the introduction of the same technology innovation (Ilie, 2005). Aggelidis and Chatzoglou (2009) argue that since an innovation is implemented in an organizational setting, the decision to adopt an IT happens first at organizational level, then at the individual user level. Various organizational characteristics influence the decision to whether or not adopt a technological innovation (Rogers, 1983; Damanpour 1992, Premkumar and Ramamurthy 1995). The size of an organization has been repetitively identified as a factor that positively influences the adoption and diffusion of innovations in several industries (Rogers, 1983; Patterson et al., 2003; Mohr, 1969; Kaluzny et al., 1973; Mytinger, 1968; Ko et al., 2008). Size has been a variable widely used when investigating organizational innovativeness. Large companies are perceived to be more experienced regarding ICT use than small ones as they can rely on more financial and non-financial resources, technological know-how and stronger infrastructures. Small organizations face significant constraints such as high competition, shortage of resources, financial struggles, as well as the lack of internal expertise (Rogers, 1983; Kimberly and Evanisko 1981; Patterson et al., 2003). Thus, the benefits of IT adoption may be greater for larger organizations than for smaller ones (Thong, 1999 in Ko et al., 2008). Organizations with an aggressive organizational strategy are more likely to adopt (Costello and Moreton, 2009). Hence, organizations with an aggressive organizational strategy are more likely to adopt an innovation (Ko et al., 2008). A number of additional organizational characteristics could also predict the adoption of a technological innovation: quality of human resources, managerial structure, top management support, organizational readiness, organizational culture, overall ICT experience and ICT commitment, and availability of financial resources (Wu, 2012; Chwelos et al. 2001; Premkumar and Ramamurthy, 1995; Iacovou et al., 1995; Grover, 1993; Fichman and Kemerer 1997; Saunders and Clark, 1992; Asif and Mandviwalla, 2005; Raufflet et al., 2005; Cooper and Zmud 1990; Karahanna et al. 1999).

Environmental factors

Some characteristics of the external environment, such as environmental uncertainty, normative influences, or government regulations (Chwelos et al. 2001; Tornatzkey and Fleischer, 1990; Teo et al. 2003), play a major role. Among external environment variables identified in the literature, we also find: dependency and trust (Saunders and Clark, 1992), external pressures (Iacovou et al., 1995) made by major business partners (Bouchard, 1993), power (Hart and Saunders, 1997), and competitive pressures (Premkumar and Ramamurthy, 1995; Premkumar et al., 1997; Wu, 2012; Chang et al., 2008; Grover 1993).

2.1.3 Beyond the adoption and diffusion of ICS: The concepts of technology acceptance, acceptability and appropriation

Bunduchi and co-authors (2011) view the adoption of innovation as “a stage process involving the generation of an innovative idea, the acceptance of that innovation represented by an organizational mandate to change and its implementation so that the innovation becomes ingrained within the organization.” This definition suggests that the concepts of acceptance and appropriation are intrinsic to the process of adoption of innovation (Bunduchi et al., 2011). However, these concepts are ill-defined and need some clarification.

Technology acceptance

The great deal of attention given to the topic of technology acceptance lies on the fact that ICTs correspond to important tools that have the capability to improve the quality of life in various social and economic contexts, including healthcare (Brangier et al., 2010). However, the introduction of ICTs into an organization could be disruptive since these innovations bring along a process of change that could trigger a re-configuration of work, skills, roles and much more. The level of centralization and formalization, the size, and the environment of an organization are some of the characteristics, which have been found to impact technology acceptance (Bobillier-Chaumon Dubois, 2009). Furthermore, design characteristics of a system can positively or negatively influence users' acceptance (Davis, 1993).

The concept of acceptance is deeply rooted in the information systems literature with the well-known technology acceptance model (TAM) proposed by Davis in 1989. TAM (and its variants- see Venkatesh et al., 2003 for a synthesis of these models) is among the most prevalent theoretical perspective used in investigations to explain and predict users' acceptance of ICTs and their intention to use these technologies (Liao et al., 2009; Kerimoglu et al., 2008; Gagnon et al., 2010; Kim and Garrison, 2009). TAM proposes that IT adoption and usage is directly determined by users' beliefs and attitudes in relation to the IT innovation (Aggelidis and Chatzoglou, 2008). Indeed, TAM has been widely used for evaluating and measuring determinants that lead to the initial acceptance of an information system and for predicting their use (Pia and Huang, 2012; Liao et al., 2009; Kerimoglu et al., 2008). More basically, TAM attempts to analyze why users accept or reject an ICT (Davis, 1989).

TAM is derived from social psychology and relies heavily on the work of Fishbein and Ajzen (1975) who proposed the theory of reasoned action (TAR). TRA asserts that behaviour is generally influenced by intentions, which are determined by both attitudes towards an action and subjective norms (Costello and Moreton, 2009; Brangier et al., 2010). Thus, behaviour arises from the following sequence: "belief-attitude-intention-behavior" (Fishbein and Ajzen, 1975 in Lee and Park, 2008). Both TRA and TAM suggest that behaviour is based on the intention to fulfill the behaviour since it is assumed that intention and actual behaviour are highly correlated (Costello and Moreton, 2009). More specifically, TAM proposes that user's acceptance of a new ICT will directly depend on the technology's perceived ease of use and perceived usefulness

(Brangier et al., 2010). Figure 2-1 presents the Technology Acceptance Model and its variants, namely TAM2, UTAUT (Unified Theory of Acceptance and Use of Technology) and TPB (Theory of Planned Behavior). In all four models, the *behavioural intention to use* or *acceptance* represents the core variable.

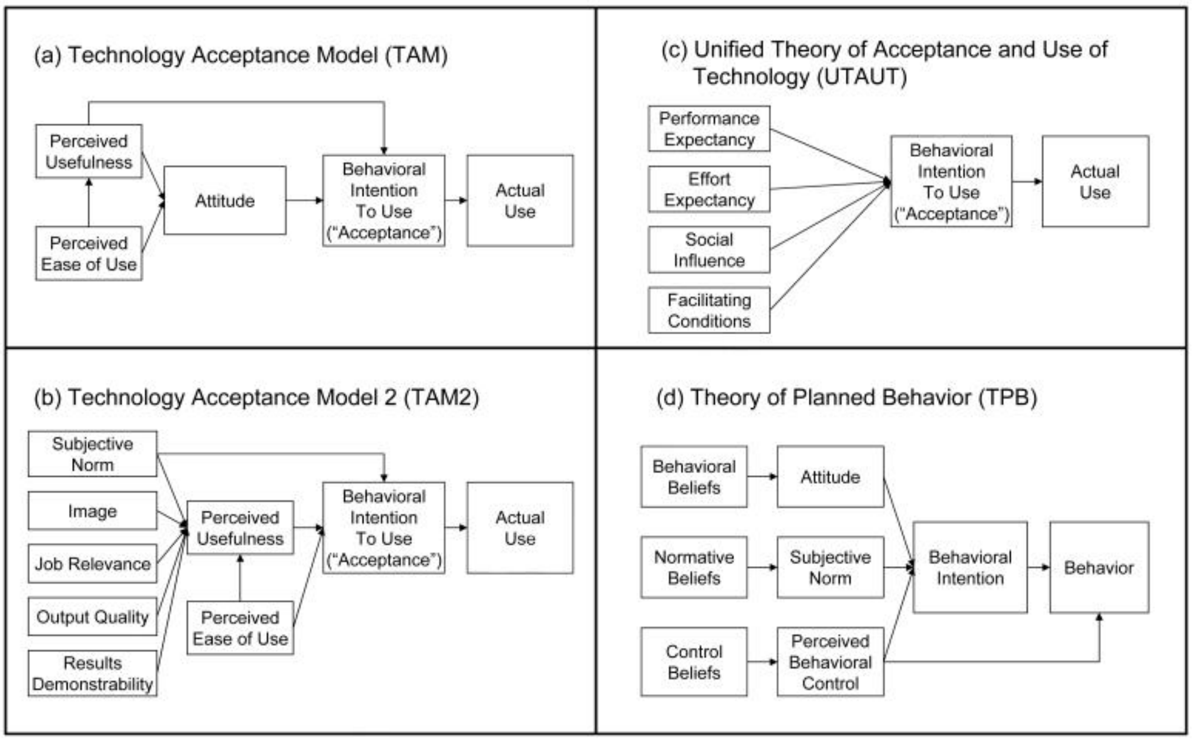

Figure 2-1 Technology Acceptance Model and its variants (Source Holden and Karsh, 2010)

In the TAM model, perceived usefulness refers to "the extent to which a person believes that using a particular technology will enhance her/his job performance" whereas perceived ease of use indicates "the degree to which a person believes that using a technology will be free from effort" (Davis 1989). Various studies have examined the correlation between *perceived ease of use and perceived usefulness* and the effects of these two variables on a user's behavior towards technology adoption (Kim and Garrison, 2009).

TAM has been applied to numerous studies in a wide variety of ICTs across different sectors (Liao et al., 2009; Kerimoglu et al., 2008; Lee and Park, 2008), including studies exploring the factors that affect consumer acceptance of RFID technology (Hossain and Prybutok, 2008) or evaluating healthcare professionals' acceptance of ICTs (Dixon and Stewart, 2000; Jayasuriya, 1998; Chau and Hu, 2002; Chismar and Wiley-Patton, 2003; Van Schaik et al., 2004). Although widely used, TAM raises some critics, including the fact that TAM does not take into consideration influences of personal behaviour, economic factors, outside influences, organizational factors and the social environment where the technology is planned to be used (Costello and Moreton, 2009; Pai and Huang, 2012; Lee and Park; 2008; Gagnon et al., 2010; Kim and Garrison, 2009; Legris et al., 2003). Consequently, some authors have questioned its applicability in fields where the social environment is known to have an impact on technology acceptance or rejection, in particular in healthcare (Gagnon et al., 2010) or in cases of "mandatory" technology adoption (Lee and Park, 2008; Brown et al., 2002)

Hendrick et al. (1984) defined technology acceptance as "an individual's psychological state with regard to his or her voluntary or intended use of a particular technology." According to Dillon and Morris (1996, p.4), user acceptance of a technology refers to "the demonstrable willingness within a user group to employ information technology for the tasks it is designed to support". Both definitions place an emphasis on individuals. It is thus not surprising that the literature in this field has centred on the understanding of "individual behaviour" (see for instance, Agarwal, 2000) and had not given much attention to the adoption "behaviour of an entire organization" (King and Gribbins, 2002).

Technology acceptability

Acceptability refers to "the question of whether the system (or technology) is good enough to satisfy all the needs and requirements of the users and potential stakeholders, such as the user's clients and managers" (Nielsen, 1993, p.24). The concept of acceptability can be viewed from a social perspective and a practical perspective. Social acceptability deals with what the "users want" (Keates, 2007, p.2) and thus includes users' impressions, attitudes, social constraints and norms leading to the individual or collective (organizational) decision to use the technology (Bobillier-Chaumon and Dubois, 2009; Brangier et al., 2010). *Social acceptability* is also directly linked to other people's opinions (Santi, 2011) and, we would like to add here, to their expectations. *Practical acceptability* comprises various factors including usefulness, cost, compatibility, and reliability (Figure 2-2). *Usefulness* entails both the notions of *utility* – i.e. whether the technology can do what is expected- and *usability* – i.e. whether the users can use the functionalities in order to accomplish the desired tasks (Nielsen 1993, 25). Usability or simplicity of use (Shneiderman, 1980) conveys that the technology is easy to learn, to use and to remember, that it generates few errors or bugs, and that is “subjectively pleasing”.

Usability as displayed in Figure 2-2 fits the definition given by Shackel (1991) for whom usability represents “the artifact's capability, in human functional terms, to be used easily, effectively and satisfactorily by specific users, performing specific tasks, in specific environments”. It is also aligned with the one proposed ISO/IEC 9126-1 where usability is defined as “ the capability of the software product to be understood, learned, used and attractive to the user, when used under specified conditions” (ISO/IEC, 2001).

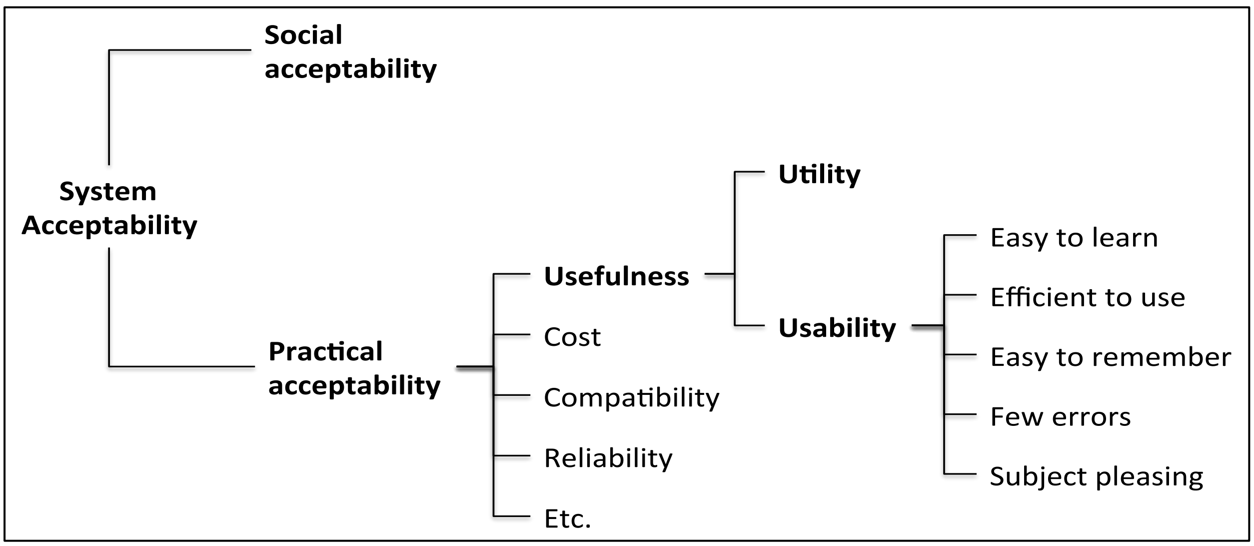

Figure 2-2 Acceptability Model (adapted from Nielsen, 1993, p. 25)

Technology appropriation

Appropriation can be traced to the theories on socio-cultural learning and human agency where different definitions of this concept are proposed. Among the multiple definitions, the one provided by Wertsch (1998) could represent the conceptual anchor in the context of ICTs. The author proposes that appropriation refers “to taking something that belongs to others and making it one’s own” (cited by Overdijk and Van Diggelen, 2006). Appropriation does not mean taking ownership of the technology, but rather adapting it to personal use. Appropriation is also as “a process in which a technology is explored, evaluated and adopted or rejected by users" (Carroll et al., 2003). This implies a process of social construction that goes beyond the proficient use of a technology or the mastering of a tool as it allows the technology itself, its meaning and effects to be shaped by users.

Appropriation takes place at the individual level and recognizes the user as an active change agent. It provides some explanations on how individuals integrate ICTs in their work practice or in their daily lives (DeSanctis and Poole, 1994; Frissen and van Lieshout, 2006; Bar et al., 2007). Appropriation can also occur at the user group level and at the organizational level. In the case of mobile phone or Internet applications, "mass" appropriation becomes societal and universal implicating individuals from different socio-economic background in almost any country and shaping the ever-evolving features of these applications.

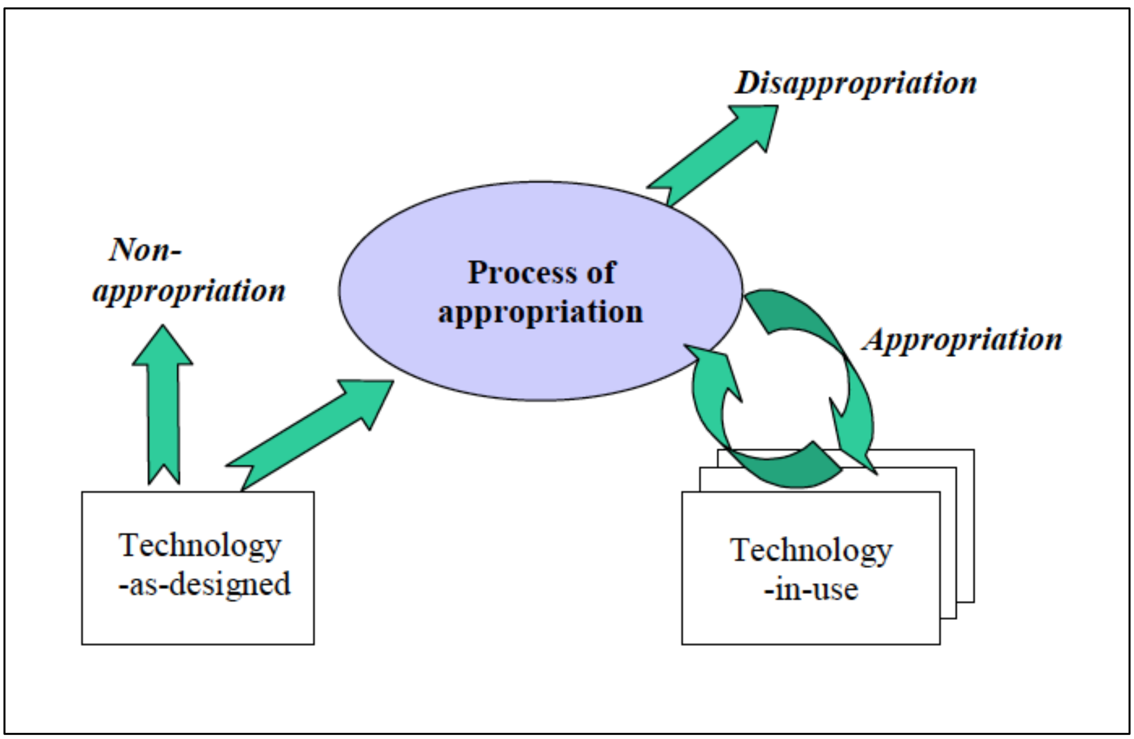

Figure 2-3 Technology Appropriation Model (Source: Carroll et al., 2002)

Technology-in-use usually differs from technology-as-designed (Figure 2-3). Technology as designed could be simply rejected without any efforts on the part of the users (non-appropriation) when, for instance, they are missing an adequate understanding of its capabilities. Technology could also go through an initial process of appropriation and be still rejected by users (disappropriation). Finally, technology could be repetitively used, and, iteratively shaped and transformed (appropriation).

DeSanctis and Pooles (1994) suggest that users could appropriate technologies in manners that were ‘‘unfaithful to the spirit of the design”. Users can severely limit the technology or in the contrary can go beyond its initial scope. The adaptive structuration theory posits that decision processes tend to be more effective if appropriations “remain faithful to the technology spirit”. Nevertheless, some authors, especially in the specific context of nomad computing, Internet and wireless technologies, lessen this assumption (Boudreau and Robey, 2005 in Cousins and Robey, 2005). Indeed, users may deal with the constraint of the technology by reinventing its intended features (Boudreau and Robey, 2005). Cousins and Robey (2005) provide an example in the context of cellular telephone technology and explain that nomadic computing users could reinvent their ways of using their cellphones. For instance, in order to save time while on the move, users could use their voicemail systems to record their ideas just as they will use a recording machine. Despite the fact that such practice was not part of the spirit of the design of such technology, it could facilitate user’s time effectiveness. This is in line with human agency theory concerning the enactment of ICTs (Orlikowski, 1992). In fact, ICTs users can circumvent technological constraints in creative and unexpected ways based on their “unique individual disposition’’ and their “temporal circumstances’’ (Emirbayer and Mische, 1998; Kallinikos 2002), even in the case of large, rather inflexible software such as ERP (Boudreau and Robey, 2005).

The innovation adoption and diffusion theories (section 2.1.1 and 2.1.2) provide core foundations to comprehend the decision of whether or not to purchase a technology, the factors that impede or promote technology adoption or the rates of adoption and diffusion. However, these theories do not attempt to elucidate the actual use of a technology (Bar et al., 2007). The concepts of technology acceptance, acceptability and appropriation seem therefore crucial. Table 2.2 summarizes the definitions found in the literature and offer the definition we will retain in the thesis.

Table 2-2 The concepts of technology acceptance, acceptability and appropriation

Concepts	Definitions	Retained definition
Acceptance	An individual's psychological state with regard to his or her voluntary or intended use of a particular technology (Hendrick et al., 1984). The demonstrable willingness within a user group to employ information technology for the tasks it is designed to support (Dillon and Morris, 1996). The extent of use of technologies on various dimensions of the professional activity (Bobillier-Chaumon Dubois, 2009).	The demonstrable willingness of an individual, a user group, or an organization to use the technology for the tasks it is designed to support
Acceptability	A situation in which the user is prompted to establish an evaluation by anticipating the cost-benefit of using a number of criteria (Bobillier-Chaumon Dubois, 2009) The question of whether the system is good enough to satisfy all the needs and requirements of the users and potential stakeholders, such as the user's clients and managers (Nielsen, 1993).	The extent to which a technology is accepted by an individual, a user group or an organization.
Appropriation	Taking something that belongs to others and making it one's own (Wertsch, 1998). A process in which a technology is explored, evaluated and adopted or rejected by users (Carroll et al., 2003). The way technology or technological artefacts are adopted, shaped and then used (Carroll et al., 2002). A process of social construction in which the actions and thoughts of the user are shaped by the technology, while the meaning and effects of the technology are shaped through the users' actions (Overdijk and Van Diggelen, 2006). A process where users make technology their own and embed it within their lives" (Bar et al., 2007).	A process of social construction that allows an individual, a user group or an organization to make the technology their own.

The concept of acceptance has been examined in-depth in multiple IS studies that are mostly based on Technology Acceptance Model (TAM) from Davis (1989). Acceptance is, without a doubt, more investigated that the concepts of acceptability and appropriation and the literature reflects this gap. In the context of this research, we propose that all three concepts seem to be highly pertinent to understand the drivers of the adoption and implementation of ICTs and particularly those related to RFID technology.

2.2 RFID

This section examines one specific ICT, namely RFID that has generated considerable hype. RFID has been termed as "tech's official next big thing" (Federal Trade Commission, 2005). It has been predicted to "change the way business is conducted and revolutionize the supply chain" and to "replace the standard barcode" (Kim and Garrison, 2010) and has been called "the barcode of the next generation" (Jones and Chung, 2008, p. 178). One of its most intrinsic capabilities lies in the level of pervasiveness it could allow. Indeed, RFID tags can be embedded in objects or individuals, and, components of the RFID can be integrated so that they seem to be invisible. As mentioned by Weiser in his influential article in Scientific American, "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 1991, p. 94). He further states that pervasive technologies "disappear into the background; (….) people will simply use them unconsciously to accomplish everyday tasks". Despite the "initial peak of inflated expectations" that is typical of any technology hype cycle (Gartner, 2013; Wang, 2010), RFID does have the potential to improve key processes in many industries. This warrants further investigation.

2.2.1 RFID technology: an overview

RFID is by no means a new technology since the British Air Force first used it during World War II. What is new however are the RFID applications that are far ranging in the most part to technological advances, decreased costs of needed infrastructure and continued efforts to establish standards (Federal Trade Commission, 2005; Castro and Fosso Wamba, 2007; Leimeister et al, 2007). RFID gained considerable momentum in the beginning of the last decade when Wal-Mart and the US Department of Defense required that their major suppliers adopt and implement RFID technology (Brown and Russel, 2007; Lee et al, 2007; Leimeister et al, 2007; Li et al., 2006).

RFID system

In its generic form, an RFID system (Want, 2004) is composed of three essential layers: (i) a tag or transponder containing a chip which is embedded in of attached to a physical object, (ii) a reader called interrogator and its antennas that communicate with the transponder without requiring the line of site and (iii) a host server equipment comprising a middleware which manages the RFID equipment, filters data, and provides information to the different organizational information systems. RFID tags uses can be active, passive, and semi-passive. Active RFID tags draw power from a battery and transmit signals to readers. They can, if necessary, monitor environmental conditions (Hayles, 2009). Passive RFID tags draw their own power from a reader. Semi-passive tags use a smaller battery to power the microchip circuitry but do not transmit a signal like an active tag. Instead the battery power is used to boost the sensitivity of the tag's microchip to enhance read rate, and in some cases perform add-on functions such as monitoring motion.

RFID capabilities

RFID is a wireless Automatic Identification and Data Capture technology (AIDC) that uses radio frequency signals in order to communicate (transmit and receive) data permitting to automatically and uniquely identify, trace and track individuals and objects without requiring line-of-sight. This capability offers the potential to generate operational improvements across a wide spectrum of industries (Kim and Garrison, 2010; Wang et al, 2010; Roberts, 2006; Curtin et al, 2007; Corchado et al., 2008, Lee et al, 2008; Brown and Russell, 2007; Leimeister et al, 2007). In particular, organizations gain with RFID the ability to obtain real-time information on the location and characteristics of tagged items, supplies, merchandise, and even individuals (Wang et al. 2006; Norten, 2012), within their own boundaries, but also across supply chains (Attaran, 2007; Goswami, 2009).

RFID is recognized as a potential successor of barcodes due to a combination of characteristics regrouped into four categories (Chao et al., 2010): i) "*uniqueness*" as RFID permits unique product identification, ii) "*timeless*" given that it allows to reduce or eliminate the time required to execute time-consuming activities such as manually scanning items, iii) "*accuracy*" since information is seamlessly captured and errors are thus eliminated or reduced, and iv) "*completeness*" as the pertinent information on items, products or individuals allows the alignment between the physical world and the virtual world. To these characteristics, we would add "*added intelligence*" as RFID-embedded objects become "a mobile, intelligent and communicating component of an organization's overall information infrastructure" (Goswami, 2009). When combined with other technologies such as embedded sensors and other mobiles technologies, RFID capabilities could be largely leveraged. For instance, the GPS technology could allow real time localization functions of an RFID system, which could be interconnected to networks and Internet, entailing that objects could be uniquely and instantaneously identified anywhere in the world; hence, allowing the shift towards what is known as "the Internet of things" (OECD, 2007; ITU, 2005, p.2). Hayles (2009) suggests that "RFID destabilizes traditional ideas about the relation of humans to the built world" since it "enables the creation of animate environments where human action becomes coordinated in an increasingly virtual manner."

RFID limitations

Despite rising interests, RFID presents some limitations such as lack of standards, technical expertise and high costs that hampers its widespread diffusion (Castro and Fosso Wamba, 2007). Furthermore, security and privacy concerns are other barriers that have to be considered. Technical challenges such as RFID integration with existing intra- and inter-organizational information system infrastructures are also considerable. Finally, the management of the high volumes of data generated by RFID system should be evaluated prior to implementation (Castro and Fosso Wamba, 2007). Indeed, the volume of data could be so large that "it may well overwhelm all existing data sources and become, from the viewpoint of human time limitations, essentially infinite" (Hayles, 2009).

2.2.2 Determinants of RFID adoption and diffusion

Determinants of RFID adoption and diffusions follow the assumption that they are similar to the ones found for ICTs in general. Such assumption holds at least to some extent. This section will focus on determinants that are more specific to RFID.

Technological attributes

The technological attributes that could facilitate or block the intention to adopt RFID take into account the five attributes proposed by Rogers. However, *complexity* and *relative advantage* stand out from the literature.

Even though there are several mesmerizing justifications to adopt RFID, the *complexity* of the technology appears to be a major stumbling block (Vic, 2006). Technical issues such as interference, multi-tag collision, signal propagation issues (LOS, shadow effect) or lack of commonly accepted standards are being addressed through years of technical advancements (Xinrong, 2010; Samno et al., 2012), but they still render RFID adoption highly complex and decrease the probability of potential users adoption (Wu et al., 2012; Vilamovska et al., 2008; Zhu et al. 2006; Vic, 2006). In a supply chain context, the levels of complexity increase as, for instance, the lack of commonly accepted standards obviously hampers the communication and management of information gathered via the RFID infrastructure (Wu et al, 2012). RFID can be integrated with other technologies such as ERP, WMS, MMS or GPS. This constitutes a double-edge sword. On one hand, it is an area of tremendous potential (Roh et al., 2009). On the other hand, this does increase the complexity of RFID adoption and diffusion. According to Steele (2004 cited in Wu, 2012), it is unlikely that a firm adopt a technology if it is perceived as too complex to integrate into its operations. Finally, RFID implementation is complex as it requires significant business processes redesigns, changes in workflows, and major investments. It even become more complex if RFID has to be integrated with existing intra and inter organizational enterprise applications, depending on the scope of the adoption (e.g. close loop vs. open loop), the latter constitute a major challenge for RFID adoption (Srivastava, 2010; Loebbecke and Palmer 2006).

Relative advantage focuses on the comparison between RFID and its rival, omnipresent and well-established technology, namely barcodes. Since RFID does not require line of sight, it becomes much easier for operators and staff to read RFID tags than barcodes. Items identified with barcodes need to be scanned, one by one, by staff (for instance, a clerk at a warehouse receiving dock). RFID tags can be read automatically as RFID-enabled items circulate through RFID-enabled zones. In the retail and manufacturing industry, these attributes bring added value to inventory management and warehousing activities. For instance, warehouse activities such as receiving, picking, put-away and shipping and carried out in a more efficient and easier manner (Lefebvre et al., 2012; Fosso Wamba et al., 2009; Bendavid et al., 2009). In contrast to barcode technology, which only identifies a class of items and one at the time; RFID permits the "unique" identification and tracking of items at the unit level without human intervention (Lai and Hutchinson, 2005). Furthermore, RFID allows scanning multiple items at the same time (e.g. many products, boxes, or pallets), a technological attribute that barcodes do not detain. Finally, RFID can withstand harsh environment, such as environments where technology will be exposed to moisture or high temperatures, and continue to be functional which is not the case for barcodes.

The *cost* of the RFID infrastructure is consistently identified as a major stumbling block that restricts a broader diffusion of RFID (Lin and Ho, 2009; Kumar et al., 2009; Kumar et al., 2010; Roh et al., 2009; Lin and Ho, 2009). Although the cost of RFID tags is falling, this is only the one small component of the infrastructure. Infrastructure hardware and software require RFID readers, servers, middleware, databases, etc. and costs add up quickly. Furthermore, changes such processes redesign, to data collection and management methods and to device management as well as the integration with legacy systems and data synchronization with business partners require extensive investments. These high costs combined with an uncertain ROI (Lee and Özer, 2009; Sarac et al., 2010; Lee and Lee, 2010; Baysan and Usttungdag, 2013) act as a deterrent to RFID adoption. RFID is thus viewed by some organization as a necessary evil.

Table 2-3 Perceived benefits of RFID adoption and diffusion (Cont.'d)

Category of benefits	Benefits	Authors
Cost savings	Reduced inventory handling costs, decreased shrinkage and theft, lower labor cost, reduced inventory cost, decreased counterfeiting, decreased logistics costs, improved management of assets.	Roh et al. (2009); Park et al (2010); Michael and McCathie (2005); Jones et al. (2004); Curtin et al. (2007); Lee and Ozer (2007); Mehrjerdi (2010); Zhu et al. (2007); Matta and Moberg (2006); Koh et al. (2006) ; Bhattacharya et al. (2007); Tajima (2007) ; Prater et al. (2005).

Table 2.3 Perceived benefits of RFID adoption and diffusion (Cont.'d and end)

Improve visibility	Increased production line visibility, increased visibility on operations, increased visibility of supply chain, improved customer relationships, increased information exchange among suppliers, improved tracking and tracing, increased data accuracy, improved visibility of orders and inventory, production tracking, improved inventory monitoring, reduced out-of-stock, reduced bullwhip effects.	Park et al. (2010); Roh et al. (2009); Mehrjerdi (2011); Bendavid and Cassivi, 2012; Sharma and Citurs (2005); Mehrjerdi (2010); Ngai et al., 2012; Higgins and Cairney (2006); Zhu et al. (2007); Tajima (2007) ; Bhattacharya et al. (2007); Koh et al. (2006) ; Prater et al. (2005); Jones et al. (2004).
Supply chain efficiency	Improved supply chain competitiveness, reduced time to market, reduced supply chain cost, reduced out of stock levels, end-to-end traceability, improved performance.	Park et al. (2010); Lefebvre et al. (2012), Bendavid and Cassivi, 2012; Bendavid et al. (2008); Datta et al., 2007.
Operational efficiency	Reduced machine down-time, decreased idle time, reduced defect rate, shorter cycle times, decreased late delivery, reduced overtime, reduced transaction errors, improved inventory management, reduced bottlenecks, reduced ordering lead time, improved resource utilization, improve management of assets, enhanced reliability and quality control, improved customer service, improved process efficiency.	Ngai et al. (2012); Mehrjerdi (2011) ; Park et al. (2010); Lim and Koh (2009); Matta and Moberg (2006); Bhattacharya et al. (2007); Tajima (2007) ; Koh et al. (2006) ; Michael and McCathie (2005) ;
Enhanced business model	Improved availability of customer data, streamlined transaction processing, closer connection between retailers and suppliers, integrated business model.	Park et al (2010); Koh et al. (2006).
New process creation	New process creation, simplified business processes, automatic no-line-of-sight scanning.	Mehrjerdi (2011); Zhu et al. (2007); Koh et al. (2006); Asif and Mandviwalla (2005)

Perceived benefits emerge from the literature as one of the most studied determinant of RFID adoption and diffusion. Given the fact that RFID is still considered an emergent technology, there is still a lack of a clear understanding of its benefits, especially in order to justify the heavy investments required for its adoption (Roh et al., 2009). Consequently, a significant segment of the literature on RFID adoption and diffusion focuses on perceived benefits (Table 2-3).

Given that the focal point of this thesis is on a "close-loop" application of RFID within one hospital, the potential of RFID to increase supply chain efficiency will not analyzed in the context of this doctoral project.

Environmental context

Some research studies indicate that *environmental characteristics* have a strong influence on RFID adoption and diffusion (Wu, 2012; Wen et al., 2009). In particular, competitive pressures and trading partner power are consistently found as the most significant environmental characteristics. In fact, organizations tend to adopt new technologies when they encounter high direct competition; new market opportunities or changing customer needs firms (DiMaggio and Powell, 1983 in Wu, 2012). Consequently, potential adopters whose competitors have already adopted RFID may be willing to adopt RFID to compete with others in the same economic situation. Literature also substantiates that the trading partner power is a major reason for firms to adopt RFID systems. For instance, mandates by Wal-Mart and the US Department of Defense (US DOD) required that their top suppliers adopt and implement RFID by the beginning of 2005 and this was the main reason for these organizations to adopt the technology at the time.

2.2.3 RFID implementation models

Our collective understanding of "how" and "why" organizations start or end RFID deployments seems to be minimal (Lutton et al., 2008). The fact that the majority of organizations investigating RFID are still in the earlier adoption stages (Roh et al. (2009) partially explain this lack of research. However, the rise of RFID adoption across a wide spectrum of industries calls for a structured approach to implement this technology. Since the existing literature on the steps necessary to implement RFID technology is limited (Kumar et al., 2010; Lutton et al., 2008), different implementation models were proposed (Table 2-4).

Table 2-4 Examples of RFID implementation models proposed in the literature (Cont.'d)

Authors	Key point	Details on the model
Brown (2007)	Business justification should be established prior to project initiation.	Four-phase implementation model for RFID: • phase 1: preliminary planning phase to mainly create project teams and define objectives. • phase 2: project team formation and pilot project. • phase 3: elaboration of RFID systems interfaces with the enterprise network. • phase 4: final rollout.

Table 2.4 Example of RFID implementation models proposed in the literature (Cont.'d and end)

Reyes and Jaska (2007)	The speed at which RFID will reach a maturity stage is influenced by both actual and perceived benefits and risks	Eight-steps RFID implementation model: • step 1: understanding RFID technology • step 2: analysis of current system • step 3: building a ROI business case • step 4: assessing the requirements for the RFID implementation • step 5: testing the RFID system • step 6: implementating the RFID system • step 7: monitoring and evaluating the RFID system once implemented • step 8: continuous improvement
Jones and Chung (2008)	RFID implementations imply a level of complexity beyond more conventional project since RFID entails "dramatic change" within the organization	Four-phase RFID implementation project life cycle: • conceptual phase: main objectives of the implementation • planning phase: outline for the implementation • installation phase: purchasing of RFID system components and physical installation start-up phase: testing and debugging to ensure system is functional
Folinas and Patrikios (2008)	RFID implies above all a in-depth understanding of existing business processes followed by some business processes transformation	Four-phased RFID implementation framework: • phase 1: business analysis • phase 2: testing • phase 3: pilot implementation • phase 4: full deployment of the system
Ngai et al. (2010)	RFID implementation framework viability is validated through a case study.	Seven-stages implementation model: • stage 1: gap identification, scope definition, and feasibility analysis. • stage 2: project team formation, including the creation of an implementation team and a steering committee. • stage 3: 'AS-IS' assessment • stage 4: business processes redesign and the elaboration of new business processes integrating RFID. • stage 5: project team evaluates influential environmental factors in order to select an appropriate RFID solution. • stage 6: system implementation, including installation and testing of the RFID infrastructure • stage 7: continuous improvement

The most complete model is the seven-stage RFID implementation model from Ngai and his co-authors (2010) (Figure 2-4). The first stage represents project feasibility and scoping and includes activities such as gap identification, scope definition, and feasibility analysis. Project team formation (stage 2) entails the creation of an implementation team and a steering committee. In 'AS-IS' assessment (stage 3), the current processes are analyzed while stage 4 entails the redesign of business processes and the elaboration of new business processes integrating RFID. For the hardware adaption to the environment (stage 5), the project team evaluates influential environmental factors in order to select an appropriate RFID solution. The system implementation (stage 6) comprises the installation and testing of the RFID infrastructure, including software and hardware components. Last, continuous improvement (stage 7) entails the continuous review of performance metrics once the RFID system has been implemented and the analysis of the users' feedback and comments. Our research design heavily relies on the RFID implementation model presented in Figure 2-4.

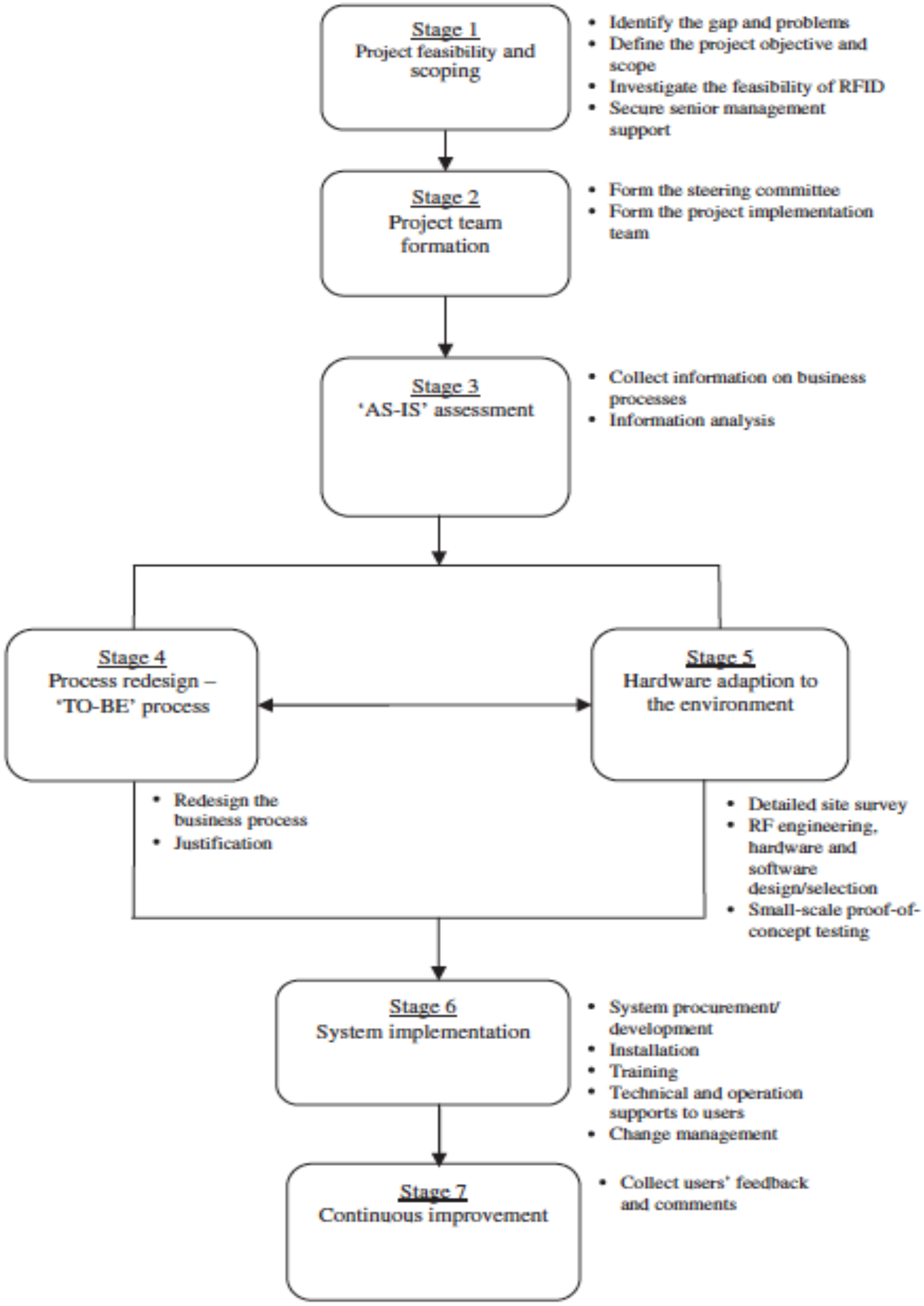

Figure 2-4 RFID implementation model proposed by Ngai et al. (2010)

2.2.4 RFID in healthcare and hospitals

Wide-ranging RFID applications

RFID could enhance the quality and reliability of health operations (Wu et al., 2013; Reyes and Jaske, 2007) since patients, staff, medicines, and critical medical equipment can be uniquely and seamlessly identified and track (IDTechEx, 2008;Li et al., 2006; Wessel, 2006). Moreover, RFID increase the integrity, safety and visibility of pharmaceutical supply chain and could be used as a mean to prevent counterfeit medicines (Lefebvre et al., 2013; Romero et al., 2012).

Healthcare seems to be "the industry" where RFID is expected to deliver the most benefits. Kumar et al (2010) refer to healthcare as "the next large industry that will embrace RFID technology and invest heavily in its implementation". RFID applications for healthcare are multiple. For instance, RFID can be used to improve patient safety by matching: i) patients and medications at bedside, ii) patients and blood products at the point of care, iii) mothers and their babies, and iv) patient and procedures at point of care (Evans, 2006 in Reyes and Jaske, 2007). Moreover, RFID can be used to locate, track and trace valuable assets across a healthcare facility improving inventory management, decreasing shortages and losses, improving staff productivity, and enhancing care delivery (Lefebvre et al., 2012). Other applications in healthcare include staff identification and location, tracking mentally-ill patients, tracking patients during health outbreaks, bed management, chemo medication management and much more (Wu et al., 2013; Lin et al., 2008; Wang, 2006; Tzeng et al., 2008; Lieshout et al., 2007; Goethals et al. 2010).

RFID-enabled asset management in hospitals

Medical devices and equipment used in hospitals are critical assets that need to be managed efficiently in order to promote their inefficient allocation for several reasons (Castonguay et al., 2012). First, they are indispensable for the accurate, prompt and adequate diagnosis, for the monitoring and treatment of patients, and in general for the vast majority of clinical acts, including surgery (U.S. International Trade Commission, 2007). In order "to deliver the right care, to the right patient, at the right time", fixed and mobile medical devices and equipment, have to be readily available whenever they are required (Litvak, 2006). Furthermore, they have to be well maintained and safe (for instance disinfected). Second, the costs associated with these devices are substantial. The worldwide market for medical devices reached U.S. $266 billion in 2011 and is projected to grow rapidly from 2013 to 2023 (Visiongain Report, 2013). Since medical equipment accounts for a significant portion of the hospitals budget, there is a strong priority to optimally manage the life cycle of these strategic assets. Third, the loss and theft of medical equipment and devices is surprisingly high in hospitals. For instance, American hospitals loose in average the equivalent of approximately U.S. $ 4000 per bed due to the theft of equipment and supplies (Lieshout et al., 2007, p. 176): with more than 975 000 staffed beds, this represent almost U.S. $4 billion. The same situation seems to prevail in most industrialized countries like the U.K. for instance (Naish, 2012).

Locating and tracking medical equipment represent key concerns in hospitals, but this has to be broadening to include all other activities related to asset management, such as monitoring their usage and ensuring their maintenance (Lampe and Strassner, 2005). Mitchell and Carlson (2001) define asset management as “a strategic, integrated set of comprehensive processes (financial, management, engineering, operating and maintenance) to gain greatest lifetime effectiveness, utilization and return from physical assets”. Assets-intensive organizations, such as hospitals, are encountering rising issues due to the sheer complexity of managing these assets (Lampe and Strassner, 2005). Hospitals, even small ones, handle on a daily basis several thousands of assets (Young, 2005). This situation is even more critical when referring to valuable mobile medical assets. These mobile assets are very diverse, ranging from infusion pumps, surgical equipment, electrocardiograms, portable x-ray machines, defibrillators to wheelchairs and rotate constantly between different medical wards. Since virtually every patient depends on one or more mobile assets during his or her hospital stay (Long and Mullins, 2010), they are also indispensable in healthcare delivery and clinical staff spends a significant share of their working time searching for these assets (Li et al, 2006a). Tracking these mobile assets is not only a time consuming activity but the inability to find them when needed is remarkably costly and possibly life threatening. The larger the hospital size, the more significant these problems get. Beside the financial implications, inefficient asset management has also deep human implications: medical and non-medical staff becomes highly frustrated due to operational inefficiencies. Technical staff loses productive hours searching for specific items that need maintenance (Li et al, 2006a), thus, the materials management and maintenance staff cannot fully meet the strict standards in maintenance (including decontamination), the medical staff cannot locate rapidly life- saving equipment such as electrocardiograms, resulting not only in lose productive hours and creating a liability issue for the hospital, but directly or indirectly in a decreasing of care quality to patients.

The main objective pursued by any healthcare system is to promote better health; however, medical errors and patient injuries occur quite too often across hospitals worldwide (WHO, 2000; Graban, 2008). A medical error refers to "the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim" while an adverse event represents "an injury that was caused by medical management rather than the patient's underlying disease" (Massachusetts Coalition for the Prevention of Medical Errors, 2006). Preventable medical errors and other adverse events constitute one of the main "causes of deaths and injuries of thousands of patients every year" (Kumar and Steinebach, 2008). The Institute of Medicine (IOM, 2001 in Nat Natarajan, 2006) reports that deaths due to preventable harmful events surpass the deaths attributable to motor vehicle accidents, breast cancer, or AIDS. A study by IBM (2008) highlights that medical error rates range from 2.9% to 45.8% for hospitalized patients out of which 27.6% to 51.2% of these medical accidents were avoidable. Iatrogenic complications or the occurrence of negative effects caused by a medical procedure (Madeira et al., 2007) also pose a serious problem. Iatrogenic complications resulting from medical equipment malfunctions are also considered a major problem (Tavakoli et al., 2007).

As a result, medical equipment should be maintained at a higher safety level than other types of equipment use in a hospital mainly due to: i) medical equipment may be used on patients who are incapable to react to hazardous conditions or pain, ii) actual electrical connection may exist between equipment and patient, iii) certain types of medical equipment are used as life support; thus, their failure could result in the patient's death (Tavakoli et al., 2007). Adequate management of these assets entails trustworthy and timely information on actual facts in order to make good decisions. However, the reality is that organizations presume that they are "doing the right things right" with no support from facts (Purbey et al., 2007).

RFID implementation models in hospitals

From their research on RFID implementation in healthcare, Kumar et al. (2010) assert that hospitals appear to pursue diversified approaches when it comes to RFID implementation (Kumar et al., 2010) and that these implementations are characterized by confusion regarding the scope, the costs and the ROI of the RFID implementation project. Models for RFID implementation in hospitals are rather scarce in the literature. A notable exception is the three-stage model proposed by Bahri (2009) that offers the notions of unfreezing, moving and refreezing. The unfreezing stage includes several activities such as setting implementation objectives, justifying the project to the hospital's senior management, forming the beta site agreement, prioritizing the RFID implementation, assigning the person in-charge of the implementation, soliciting RFID requirements for the hospital, and fitting RFID into the existing process. The moving stage is concerned with activities such as with the support of the IT Department, developing a reliable system, producing instruction manuals, training the doctors, nurses and administrative staff, managing resistance, obtaining users' feedbacks and vendor support, as well as ensuring RFID project champion. The last stage, the refreezing stage, involves securing the RFID system, monitoring of the system, regular correspondence with the RFID vendor, and continuous improvement to the system.

Kumar et al. (2010) offer some complementary insights by analysing the group of assets and individuals that will be tag across time. According to their model, the first stage (stage 1) comprises the tagging of costly movable equipment with active RFID tags. In stage 2, other objects such as surgical instrument, and other equipment are equipped with RFID and individuals, including patients, doctors, nurses, technicians, other hospital personnel, are also tagged. Stage 3 implies that all inventoried supplies will be added to the RFID system. Kumar et al. (2010) developed these three stages by taking into consideration four factors, namely: i) difficulty, ii) cost, iii) ROI, and, iv) results. Stage 1 yields the most results with the lowest costs, entails a positive ROI and less difficult to implement while stages 2 and 3 are more ambitious.

This chapter offers the possibility to transfer some conceptual notions from the broad ranging literature on ICTs to one specific ITC, namely RFID. It also sheds some light on RFID adoption and diffusion in healthcare and hospitals and demonstrates the importance of mobile assets management in hospitals. The next chapter is devoted to the research design.

CHAPITRE 3 CONCEPTUAL MODEL AND RESEARCH DESIGN

This third chapter exposes the proposed conceptual model and the related research propositions (section 3.1). It also examines the main characteristics of the research design that outlines how the conceptual model and the research propositions are investigated (section 3.2). The last section (section 3.3) presents the three thesis articles, their relation with the conceptual model and their main objectives.

3.1 Proposed conceptual framework

The proposed conceptual framework arises from the problem statement, the research questions, the context of inquiry and the literature review. It should be viewed here as a starting point for reflection and a mean to guide subsequent research activities.

3.1.1 Problem statement and research questions

The problem statement is as follows: Mobile asset management in hospitals is critical, but it is far from being efficient and RFID holds the potential to improve mobile asset management. This thesis seeks to understand why RFID is implemented and how RFID implementation is carried out. The literature appears to be biased or "short sighted" as it tends to focus on the rather simplistic perspective of adoption vs. non-adoption rather than investigating "why an organization might have accepted RFID technology due to various reasons, but it still does not fully adopt this technology" (Sharma et al., 2012). The very way RFID is implemented determines its success and the importance of how to implement RFID into healthcare is repeatedly stressed by several authors (Wu et al., 2013; Yao et al, 2012; Buyurgan and Hardgrave, 2011; Li et al., 2010; Mehrjerdi, 2010). Indeed, the lack of studies on how RFID could be implemented in hospital settings constitutes one core motivation for this research. The thesis also attempts to answer the question so what? The benefits derived from RFID may be inflated due to techno hype (Wang, 2010) and need to be more closely investigated. Does RFID really improve mobile assets management?

Answers to the above questions need to take into consideration the context of inquiry -i.e. technology implementation in hospitals- that poses unique challenges given the intrinsic characteristics of the professional bureaucracies (Chapter 1). From the literature review and the analysis of existing theoretical models or perspectives, one can also realize that there is a need to better understand the factors contributing to technology acceptance, acceptability and appropriation (Chapter 2, section 2.1). Furthermore, despite the wealth of studies concerning ICT adoption and diffusion, the ICT implementation process tends to be overlooked (Chapter 2, section 2.1.1). Because the research on RFID with the first publications in 2002 is still "in its infancy" (Sharma et al., 2012; Bhattacharya, 2012; Wu, 2012), our collective knowledge on RFID adoption, implementation and diffusion **i**s lacking.

3.1.2 Research propositions and conceptual model

Figure 3-1 shows that the research propositions (P1, P2, P3, P4, and P5) are intrinsically linked to the conceptual framework. This framework specifies the context of inquiry, namely the hospitals as professional bureaucracies and the retained RFID application-i.e. mobile assets management-(upper part of figure 2). It also addresses the three research questions: Why hospitals implement RFID? How they implement RFID? What are the benefits derived from RFID? Finally, we propose that the answers to these three questions are influenced by RFID acceptance, acceptability and appropriation (bottom part of Figure 3-1).

The five research propositions (Figure 3-1) can be read as follows:

Proposition 1: The organizational context (hospitals as professional bureaucracies) and type of RFID application (mobile assets management) have an influence on the factors driving or hampering RFID implementation, on the impacts and benefits resulting from implementing RFID and on the future RFID implementation (relationships explored by P2, P3, and P4).

Proposition 2: Some factors are highly influential. Hence, they are driving or hampering the decision to implement RFID and the implementation process.

Proposition 3: Different impacts and benefits (perceived or real) are derived at the different stages of the RFID implementation.

Proposition 4: The impacts and benefits derived from RFID implementation modify the relative importance of factors driving or hampering future RFID implementation.

Proposition 5: The level of RFID acceptance, acceptability and appropriation at the organizational level has an influence on the relationships explored by P2, P3, and P4.

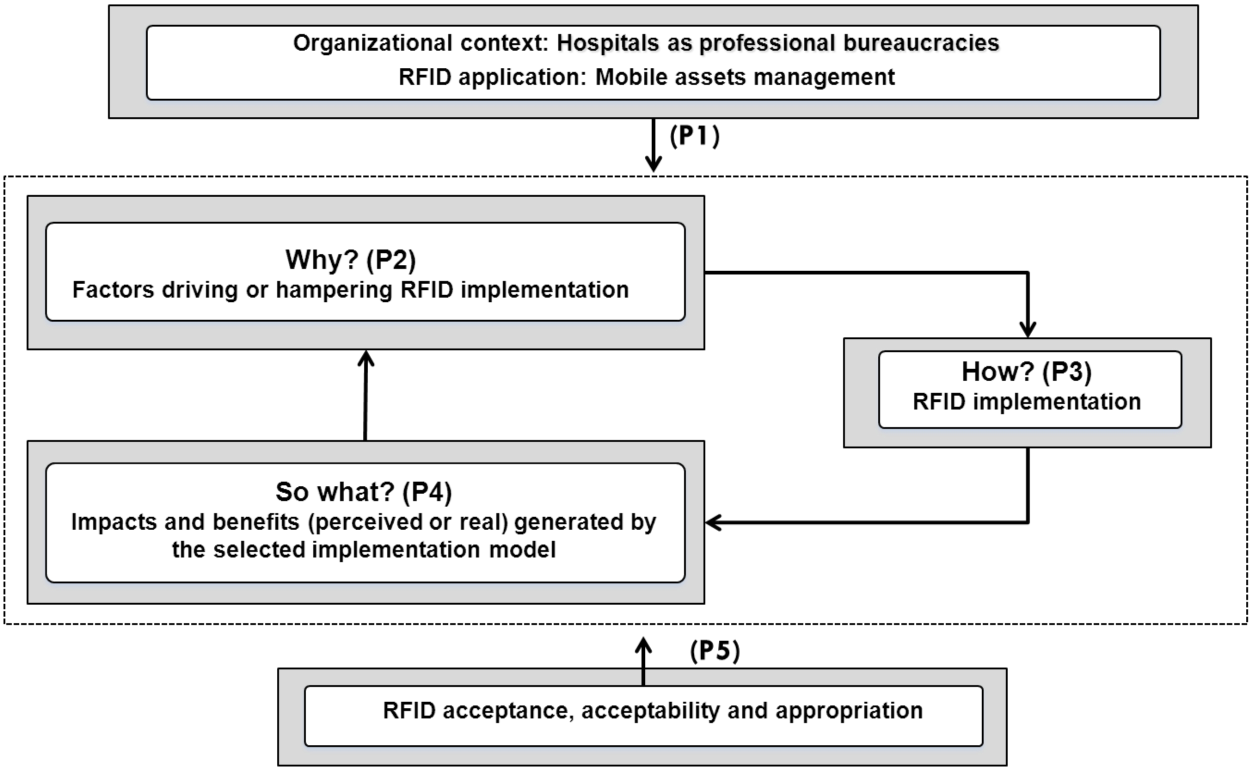

Figure 3-1 Proposed conceptual framework

3.2 Research design

In order to characterize the research design, we will argue that it is an exploratory initiative based on action research and conducted in a longitudinal single fieldwork case study. This statement obviously requires some justifications.

3.2.1 An exploratory initiative

The research design corresponds to an exploratory research initiative (Yin, 2002) as it attempts to answer questions such as Why? How? So what? These research questions are also in line with grounded theory (Glaser and Strauss, 1967; Glaser, 1992). The main objective here is to gain new insights through an inductive thinking derived from empirically based evidence (Martin and Turner, 1986, p. 141).

3.2.2 Action research vs. the living laboratory concept

Due to its inherent capabilities that differ significantly from its rival technology, namely the well-established and widely accepted barcodes technology (Chapter 2, section 2.2), RFID is considered as a disruptive technology (Lefebvre et al., 2012; Romero et al., 2012; Soon and Gutiérrez, 2008; Krotov and Junglas, 2008). By definition, disruptive technologies like RFID entail changes that do not fit the current vision. This is the primary rationale to retain research methods that allow capturing the complex dynamics of such changes. Both action research and the living laboratory concept offer the possibility to identify, examine and assess changes before and after a RFID pilot project or a RFID implementation. Both methods need clarifications.

Action research

Action research was initially used in the social sciences and in the medical sciences. It was only introduced in IS research in the late 1990s (Baskerville, 1999). Among the multiple definitions of action research, we will retain the one that we believe to be the most accurate and complete: "Action research assists in practical problem solving, expands scientific knowledge, enhances actor competencies, is performed collaboratively in an immediate situation, uses data feedback in a cyclical process, aims at an increased understanding of a given social situation, is applicable for the understanding of change processes in social systems, and is undertaken within a mutually acceptable ethical framework" (Hult and Lennung, 1978 in Vries, 2007). From this definition, four main principles arise:

1) Action research is particularly concerned by change. "The fundamental contention of the action researcher is that complex social processes can be studied best by introducing changes into these processes and observing the effects of these changes" (Baskerville, 1999, p.4). Participants (including researchers) are collectively involved to observe, appraise and evaluate a real –life situation ("as is") and they collectively find a solution to improve this situation (Van Beinum, 1998). They then induce a change in order to improve the "as is" situation and evaluate the effects of the induced change. Since "action research is primarily applicable for the understanding of change processes in social systems" (Baskerville, 1999, p.4), it seems particularly relevant to investigate information systems in general (Puaro et al., 2010; Goldkuhl, 2011; Baskerville and Myers, 2004), and, RFID implementation in particular. Let us mention that action research seems to be

rarely mentioned as the primary research method in articles on RFID (for a notable exception, see Unnithan et al., 2012).

2) The "juxtaposition of action and research" is required. Action research thrives on this duality by involving both an "intervention in real-world settings" as well as the "development of scientific knowledge" (Vries, 2007). It thus attempts to comprehend and manage the 'relationship between theory and practice' (Ottosson, 2003), taking into account that "theory informs practice, practice refines theory, in a continuous transformation" (Gilmore et al., 1984, p.161). This cyclic transformation which is central to action research is based on a number of steps that may vary: five cyclical steps, namely diagnosing, action planning, action taking/intervention, evaluation and learning/reflection (Baskerville, 1999) or four phases- i.e. planning, action, observation and reflection- (Estay-Niculcar and Pastor-Collado, 2002). The five steps from Baskerville seem to better be aligned with an RFID implementation and are retained here.

3) Action research is highly interactive, participative and collaborative as it is based in joint involvement, joint action, and shared responsibilities (Gustavsen, 1992; Van Beinum et al., 1996). Moreover, a strong emphasis is placed on joint learning that reinforces and improves the competencies of participants.

4) Action research relies heavily on qualitative data and analyses. This does not exclude quantitative data (for instance, raw data from the RFID tags) but "the full set of quantitative operations is not entirely legitimate for such use without qualitative interpretation through mapping, indexing and scaling" (Halfpenny, 1979). Moreover, this does not mean that qualitative data cannot be transformed into quantitative data (for example, simple frequencies could be derived from counting the number of the sub-processes that are eliminated, automated or improved with RFID).

Researchers may play different roles, which can be located in a continuum from complete observers to complete participants. In a field research, they may be involved in different roles covering the whole spectrum of this continuum. In action research, non-conventional roles such as change agent, facilitator, or designer are requested from the researchers (Stringer, 2007). This obviously puts significant pressures.

Living Labs

The living laboratory corresponds to an open innovation approach (Wolfer et al., 2010; ECISM, 2009) as stakeholders are involved to concurrently explore, develop, experiment and test new ideas, new products or new technologies (Kusiak, 2007) either in a laboratory that replicates real-life settings or in a well-defined territorial context. It can be applied to the different stages of an innovation, from the initial idea to recycling. It is also particularly relevant for studying and analyzing the adoption of innovation, especially the front-end phase of innovation adoption (Bendavid and Bourgault, 2010).

The living lab approach has been successfully applied to study RFID deployment, either in closed loops or across the supply chains (Bendavid and Bourgault, 2010; Wamba, 2012). In particular, "the living laboratory represents an alternative research environment, which is particularly well fitted for exploring emerging phenomena such as RFID–enabled supply chain management models as it provides appropriate support to networked innovation collaborative processes" (Bendavid and Cassivi, 2012, p.94).

From the above discussion, we conclude that action research and living lab represent both innovative and non-conventional research approaches that are relevant to gain an in-depth understanding of RFID deployment. They also share some of similar core characteristics such as a real-life situation, a participatory design and a joint involvement of all participants. One could even argue that the living lab approach is a subset of action research. We propose here that research action is suitable for exploring our research propositions since RFID implementation within the very complex and even "chaotic" environment of hospitals (chapter 1) that may raise specific and unique challenges. Further, we also suggest that the living lab approach may be perceived as experimental while action research falls into the interpretive paradigm.

3.2.3 Longitudinal single fieldwork case study

This research entails a single case study. Let us first define the term "case study". Yin proposes that "the case study method allows investigators to retain the holistic and meaningful characteristics of real-life events—such as individual life cycles, small group behaviour, organizational and managerial processes, neighbourhood change, school performance, international relations, and the maturation of industries" (Yin, 2009, p 4). This definition can be easily translated to our research and we could paraphrase Yin's citation by stating that we intend "to investigate holistic and meaningful characteristics of real-life events" related to the implementation of a specific RFID application within one hospital. The selected single case is therefore the RFID implementation and not the hospital, the latter being the primary research site.

Case study research is particularly relevant to answer research such as How? Why? (Yin, 2009). It is well documented (Gagnon, 2012; Corbin and Strauss, 2008; Gomm et al., 2002) and well-accepted in many disciplinary fields, including management (Dul and Hak, 2012), software development (Mockus et al., 2000) and information systems (Orlikowski and Baroudi, 1991). It is also heavily used in RFID adoption research (Ngai et al., 2010; Fosso Wamba, 2011).

As the proposed conceptual framework (Figure 3-1) stresses the need for investigating changes over time, it naturally points to a longitudinal case study. Data collection for the case study lasted 25 months.

3.2.4 Participating organizations and participants

This research addresses complex issues and consequently involves multiple organizations (Table 3-1) and requires for the input from thirty-five (35) participants (Table 3-2). Some additional persons who are not listed in Table 3-2 provided punctual information or validated a specific procedure: they therefore acted as punctual informants as their involvement required a few minutes of their time and at the most two hours. Such input allows a more holistic perspective on the RFID deployment.

Table 3-1 Participating organisations (Cont.'d)

- **A Dutch hospital**, called hereafter NL hospital, where the real-life site RFID implementation is taking place. It also represents the primary observation site where observations, semi-structured interviews, focus groups and panels took place.
- **A Canadian SME** with strong expertise in software development and deployment of RFID applications (Firm X). This company provided the professional expertise needed to define, validate and implement the RFID technological scenarios.

Table 3-1 Participating organisations (Cont.'d and end)

- **An American firm** recognized as a global market leader in asset visibility solutions (Firm Y). This company acted as a partner of the Canadian SMEs and was responsible for providing the hardware and software components of the RFID solution to be implemented by the Canadian SME at the NL hospital.
- **A Dutch SME** whose core competences lie in RFID components (Firm Z). This company provided inputs into the different technological solutions in terms of hardware.
- **An U.K. based subsidiary** of a company based in Japan and the business partner of the Canadian SME (Firm V). This company acted a partner of the Canadian SMEs and was responsible for providing support in terms of the specificities corresponding to European context.
- **A non-profit organization representing Dutch hospitals** (an association of Dutch hospitals), called hereafter NPO. This organization, through its Chair, was responsible for facilitating the establishment of the necessary links with the hospital.
- **One Canadian university-based research centre** with expertise on technology management and, more specifically, e-commerce, e-collaboration and RFID technologies. Researchers from this research center were actively involved in all project phases and carried out on-site observations, semi-structured interviews with hospital participants, participated to the focus groups, participated in site surveys, and collaborated in the development of technological scenarios.
- **One Dutch university-based research centre** with expertise on innovation management. Researchers from this research center were actively involved in the facility management and logistics reengineering aspects of the RFID implementation.

Among the eight participating organizations, three are Canadian, four are Dutch (including the hospital), one is American and one is from the UK. All communications (written or oral) were made in English with the only exception concerning the some internal documents written in Dutch, which were translated into English. The size of these organizations differs widely ranging from a few employees (NPO) to a rather large organization of more than 3000 employees (Dutch hospital). Cultural differences (European vs. Canadian organizations) and the influential power usually linked with the size of the organizations may raise some minor issues that are discussed in chapter 7. As mentioned in Table 3.1, all organizations with the exception of the Dutch hospital, act as technological and non-technological partners for the implementation of the retained RFID application. As the implementation is limited to the hospital, it is referred as a closed-loop implementation.

Table 3-2 Profile of key participants

Type of organisation	Organisation	Type of participant	Participant	Number of participants
Healthcare organisation	NL hospital	Hospital administration	Hospital director	1
		Biomedical	Manager, biomedical department	1
			Biomedical engineers	2
		Clinical professionals	Ward managers	2
			Team managers	5
			Head nurses	3
		ICT department	Manager of automation	1
			ICT manager	1
			Technical expert	1
		Support services: Stores	Supervisor	1
			Clerk	1
Canadian SME	Firm X	Management	Director	1
			Manager	1
		Other professionals	Technical experts	3
American firm	Firm Y	Professional	Director, Healthcare sector	1
			Technical expert	1
Dutch SME	Firm Z	Professional	Technical expert	1
U.K. based subsidiary	Firm V	Consultant	Technical expert	1
Non-profit organization	Dutch NPO	Management	Chairman	1
University-based research centre	Canadian university-based research centre	Management	Director	1
		Researchers	Full professors	2
			PhD Candidate	1
	Dutch university-based research centre	Researchers	Full professor	1
			Ph.D. Candidate	1

Note: Names are removed in order to protect the confidentiality of the participants

The profile of key participants is very diverse (Table 3-2). Nineteen (19) participants (54%) are from the primary observation site (the Dutch hospital) and belong either to the clinical side, to the administrative side or to the technical and support side (ICT, manager of medical technical department, biomedical engineers and support staff). Some participants with clinical or technical expertise are also responsible for their units or wards and act as mangers (this is the case for the manager of the biomedical department and the two ward managers). The wide-ranging expertise of participants from the Dutch hospital and their corresponding minds sets that go beyond the cleavage between non-clinical vs. clinical staff, proved to be significant in the RFID implementation. This discussed in detail in the thesis articles.

3.3 Data collection methods, types of data and data recording issues

3.3.1 Data collection methods

Data collection occurred over a two-year period (25 months more precisely). The Canadian research team went back and forth to the Netherlands on five occasions for extended periods of stay in order to participate to the on-site activities, including semi-structure interviews, observations, etc. Progress could be also traced virtually with multiple electronic exchanges with the other participants (e-mails, electronic documents, etc.). In particular, RFD data was forwarded back and forth.

Since multiple data collection methods allow data triangulation (Yin, 1994; Miles and Huberman, 1994), we relied on several sources of empirical evidence during this 25 months period, namely 1) internal documents such as clinical and non-clinical procedures and directives and external documents, 2) multiple on-site observations and 3) data generated by RFID tags and the corresponding RFID reports, 4) focus groups and panels (almost the same individuals over a two year period, including researchers), and 5) semi-structured on-site interviews.

3.3.2 Types of data

Most empirical data collected during the 25 months period represents primary data- i.e. original data collected by the researchers. Primary data arise from the multiple on-site observations carried out, the semi-structured interviews conducted, the focus groups and the panels. Primary data allow an in-depth knowledge of the existing operations of the hospital, focusing on mobile asset management, as well as a key opportunity to point-out unique areas for improvement that would not have been assessed otherwise. Semi-structured interviews were in line with previous RFID research in healthcare (Ngai, 2008) and proved to be quite insightful, especially in terms of gaining process knowledge and rethinking current practices (Table 3-3 provides an extract from the interview guides). Focus groups and panels are aligned with action research as they structured joint decision processes, collaborative actions and the analyses of changes.

Table 3-3 Extracts from the interview guides used during the semi-structured interviews

- **Examples of questions regarding the unavailability of infusion pumps (questions were repetitively asked to participants from different units, services and departments).**

Why are infusion pumps unavailable? Any other reasons?

How do you proceed to find unavailable infusion pumps? Who is responsible for searching for unavailable pumps? How often do you search them? How much time do you spend searching for IV pumps? How can the search be improved?

How much time the staff from other units or departments spend searching for IV pumps? How can the search be improved?

- **Examples of questions regarding mobile asset management processes. Below, are examples of the questions for one specific process, namely the restocking process. Similar questions were repetitively asked for each process regarding mobile asset management to participants from different units, services and departments.**

Do you agree with the overall process of mobile equipment restocking for mobile assets? Regarding infusion pumps?

Does the process of restocking assets reflect the reality of the way the tasks are performed and the way should be performed? (The process maps are being displayed during the interview for a visual anchor).

Does this specific process of restocking infusion pumps reflect the reality of the way the tasks are performed and the way should be performed? Is the process efficient? Inefficient? Why? Could it be improved? How?

What is the existing procedure when an infusion pump fails to work properly? When there is a simple problem with a pump, do you attempt to fix it yourself? How? By restarting them? Do you call the technical department when the message on the infusion pump indicates that a serious problem has occurred? Do you leave some indication that the pump is defective on the pump itself? How much time does it usually take before a defected pump is picked up for repairs?

Secondary data – i.e. data collected from existing documents, from the RFID system, etc. - also receive special attention (see Table 3-4 for an example). Some of the existing documentation was available in Dutch as it was provided by the NL Hospital; thus, this information was translated into English so that it could be shared among all project participants could. We believe that the interplay between primary data and secondary data reinforces their mutual validity, leading to more robust results.

Table 3-4 Example of secondary quantitative data - Extract from a report generated from the RFID asset management system

Event Viewer

▸ Search

Event ID	Event Monitor Name	Type	Severity	Asset Name	Location
421	In Hospital (183)	Entrance/Exit	Normal	P01 (180)	Hall
420	In Wing B (181)	Entrance/Exit	Normal	P01 (180)	Wing B
419	In Hospital (184)	Entrance/Exit	Normal	P01 (180)	Elevator
418	In Wing A (180)	Entrance/Exit	Normal	P01 (180)	Wing A
417	In Hospital (184)	Entrance/Exit	Normal	P01 (180)	Elevator

Note: By default, the list of events is sorted chronologically (newest at top)

As it is usually the case in fieldwork research, empirical evidence emerges from quantitative and qualitative data. In fact, the combination of quantitative and qualitative data "can be highly synergistic" (Eisenhardt, 1989). Quantitative data basically comes from the analysis of internal documents, the transformation of qualitative data into quantitative such the frequency of specific events and from the analysis of the raw data generated by the RFID systems. Qualitative data mainly arises from the transcripts of interviews, focus groups and panels.

3.3.3 Issues with data recording

Multiple data collection methods involving eight organizations and 35 participants for over a two-year period appear to be an appropriate research strategy. However, such strategy creates problematic issues with data recording. They also generated enormous (one might say overwhelming when taking into account the RFID data) quantities of data that had to be recorded, analysed, and, following the core principles of action research, discussed, reanalysed and revisited. A rigorous recording protocol was thus established and includes a research journal, field notes, and data analyses. Tables 3-4 and 3-5 and Figures 3.2 and 3.3 give snapshots of the recording process put in place in the context of this research. In the research journal, detailed research activities were first recorded and were then summarized. Table 3.5 gives an extract of such summaries.

Table 3-5 Extract from the summary of activities as recorded in the research journal

Overview of activities
Dates: Oct 1st – Oct 3rd
Overview:
The survey visit consisted of a site visit (1/2 day), an RFID site survey (1 day), a presentation to hospital management and follow-up meeting (1 day).
Participating organizations: NL hospital, Firm X, Firm Y, Dutch NPO, Canadian university-based research centre, Dutch university-based research centre.
Summary of activities

1) **Activity:** Process Analysis
   Participants: 1 technical expert (Firm X), 1 technical expert (Firm Y), 2 Ph.D. candidates (Canadian and Dutch university-based research centres).
   Overview: Observations of the physical movements of intravenous pumps
2) **Activity:** RF Finger Printing
   Participants: 1 Technical expert (Firm X), 1 technical expert (Firm Y), 1 Ph.D. candidate (Canadian university-based research centre).
   Hardware: ROHDE & SCHWARZ FSH6 Spectrum Analyzer.
   Overview: Walk through of specific areas in the hospital to measure possible interference and Wi-Fi coverage.
3) **Activity:** Visual Analysis
   Participants: 1 Technical expert (Firm X), 1 Ph.D. candidate (Canadian university-based research centre).
   Hardware: Canon SD1000 Digital Photo
   Overview: Strategic photos taken of environment to evaluate installation and potential interference of objects.
4) **Activity:** Meeting with Network Specialist
   Participants: 1 Technical expert (Firm X), 1 technical expert (NL hospital), 2 Ph.D. candidates (Canadian and Dutch university-based research centres).
   Overview: Discussing wireless network and features of it.
5) **Activity:** Meeting with upper management
   Participants: 1 manager and 1 technical expert (Firm X), director, manager of medical technical department, ward managers, 1 technical expert (NL hospital), 2 Ph.D. candidates (Canadian and Dutch university-based research centres), 2 full professors (Canadian and Dutch university-based research centres and Dutch university-based research centres), and chairman (Dutch NPO).
   Overview: Overall process of the RFID pilot installation, timelines, and forward looking step

Important conclusions

- Follow-up is tentatively scheduled for Oct 22nd
- The hospital team is awaiting wireless access point positioning data from the firm X
- Questions regarding SSID singularity of access points, Channel Usage, and SSID broadcasting are still pending
- Map with detailing location of access points is still pending
- Walls are brick (8-12 inch) what looks like double bricked
- Wi-Fi coverage is weak inside rooms

Third party is intended on installing the wiring prior to arrival on October 22.

In addition to the research journal, an indexed field notes journal was kept. The field notes reflected the individual and the group perspectives on the different issues related to the RFID implementation. The individual perspective includes for the most part the interview transcripts typically found in field research work. Interview transcripts are essential here because they allow direct quotes that exemplify the interpretations made in the three thesis articles, add richness to those interpretations and "give the participants a "voice" in the research" (Schultze and Avital, 2011). Field notes from the group perspective dealt with documents resulting from joint actions and from collaborative decision making processes (see Figure 3-4 for an example). Participants had to select one type of mobile assets that could be tagged in the hospital with RFID. Infusion pumps for the RFID implementation were collectively agreed upon based on different factors such as the risks they entail, their costs, their depletion rates, etc. In particular, the risk assessment score as evaluated by the participants was high for the infusion pumps (36 out of maximum score of 45 or 80% - Figure 3-2) and provided the justification to select infusion pumps for the RFID implementation. Figure 3-2 also illustrates one crucial point: it shows how collective actions or decisions can be structured.

Risk Assessment System

Name of equipment : **Infusion pump**
Type :
Manufacturer :

A. Function
10 Treatment-Life support
9 Treatment- Intensive Care Surgery
8 Treatment - Physical therapy or treatment
7 Diagnostic - Intensive or Surgical Care
6 Diagnostic - Other monitoring
5 Analytical - Analytical Laboratory
4 Analytical - Laboratory accessories
3 Analytical - Computer-related accessories
2 Diverse - Patient related
1 Diverse - Non-Patient related

B. Consequence (patient) of sudden defect
8 Potential risk of patient death
6 Potential risk of patient injury
4 Wrong diagnosis or therapy
2 No noemenswaarding risk

C. Consequence (business process) of sudden defect
5 All (related) activities until aborted object is repaired
4 Treatment of patient stopped until object is repaired
3 Treatment of patient can be prosecuted, however, some annoyance
2 Not involved in treatment of patient
1 Not involved in business process

low risk: 20, medium risk: 32, high risk 33 or higher

D. Environment
5 Anesthesia
4 Critical care
3 Wet locations Laboratories-
2 General care
1 No relation to patient

E. Required/desired preventive maintenance
5 Monthly
4 Quarterly
3 Semiannual
2 Yearly
1 Not required

F. Frequency of Usage
4 Daily
3 Weekly
2 Monthly
1 Occasionally

G. Several users
3 Different departments
2 Several users
1 Solid user

H. Trend (mean time between failure-MTBF)
5 < 3 Month
4 ± 6 Month
3 ± 1 Year
2 ± 3 Year
1 > 5 Year

Total score: 36

Figure 3-2 Extract from the field notes – Justification for selecting infusion pumps for the RFID implementation (Risk assessment analysis used by the hospital)

Field notes contained several visual displays such as self-explanatory pictures illustrating a critical issue prior to RFID implementation such infusion pumps being stored in a non- dedicated area while they should have been located in the storage room (Figure 3-3). Visual displays were also particularly useful in elaborating different RFID scenarios. For instance, the hospital plan integrating the access points and the wireless areas (Figure 3-4) spoke to all participants. The hand-written comments on the plan came directly from the activities recorded in the research journal and displayed in Table 3-5.

Picture 36
Temporary Storage of Pump in Room for Nurses
(Ref: Picture 51)

Picture 43
Intravenous Pump Storage Area
(Ref: Picture 58)

Figure 3-3 Infusion pumps being stored in a non- dedicated area

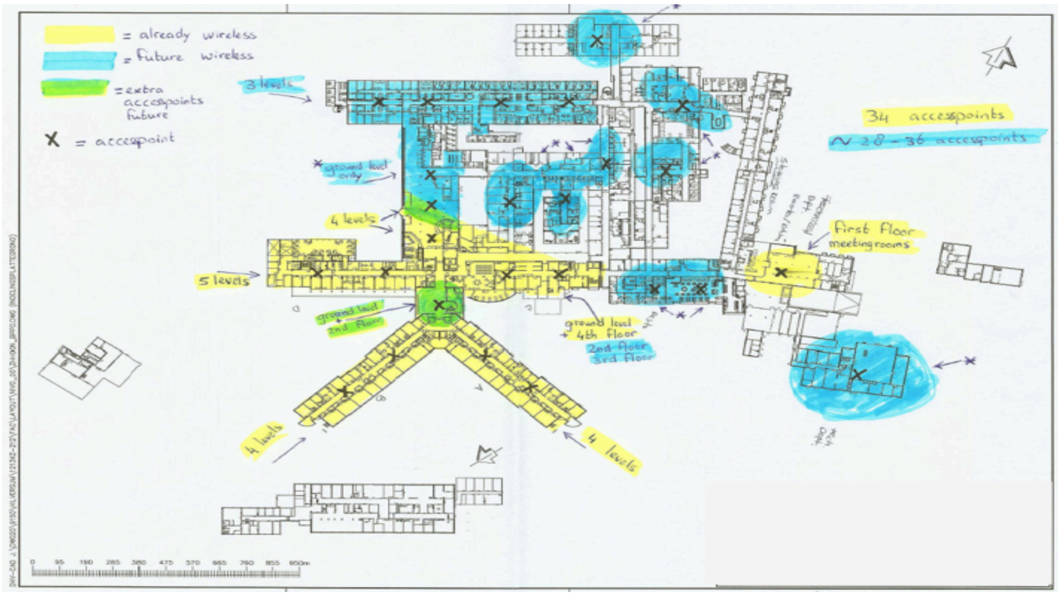

Figure 3-4 Access points and wireless areas in the hospital - A first analysis of the current state and the future needs

3.3.4 Processes as the unit of analysis

Motivations for selecting processes as the unit of analysis

We believe that business process is particularly pertinent as unit of analysis in the context of this research for three main reasons. First, the process centric analysis is one of the prominent method to study organizations in research in the IS field (Eatock et al., 2000). Davenport (1993, p. 5) defines business processes as "a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs." Further, Hammer and Champy (1993) state that business processes are "series of interrelated activities that take an input, add value to it, and produce an output that is of value to the customer". Second, RFID is considered a « transformational technology » (Hanebeck, 2004) that allows the emergence of innovative and efficient processes. However, the level of improvement that could be potentially attained by integrating RFID into existing processes implies significant, sometimes "dramatic", change to the ways an organization is used to work. Thus, RFID adoption implies the development of new "redesigned" or "reengineered" processes (Wu, 2012). Third, process mapping allows to structure masses of qualitative data into a structured visual display that serves as a powerful tool for data analysis and increases the interactions between participants. In the context of this research, we thus rely on a process centric approach in order to investigate the impacts and benefits that RFID can bring into asset management processes. Using appropriate methodologies and tools to analyse, design and visualise business process have been identified as key elements for successful BPR implementation (Al-Mashari and Zairi, 1999). Information flowcharts, infrastructure and network blue prints, and business process maps are among the tools used by Bendavid and Cassivi (2010) to evaluate RFID in the supply chain context.

Process structure and mapping

Processes were mapped using an Event-driven Process Chains (EPCs) formalism as described in Bendavid and Cassivi (2010). Process mapping represents an efficient tool not only to design and understand the current processes, but also to i) validate with project participant the information gathered during field observations and interviews, ii) easily share collected information with project stakeholders, iii) evaluate current situation and look for areas of potential improvement, iv) build and validate potential technological scenarios, v) conduct gap analysis, vi) formalized and communicate selected technological scenario, vii) present research results to project's participants, and viii) diffuse results to the research community.

The processes mapped during this research were modeled using the logic proposed by IDS Scheers and its related tool set named Aris. The basic elements of a process from an event input to an event output are clearly identified in Figure 3-5. They represent the affected resources, the concerned functions and the needed information (from an information system and from a data carrier). Process maps displayed in the thesis articles reflect this logic.

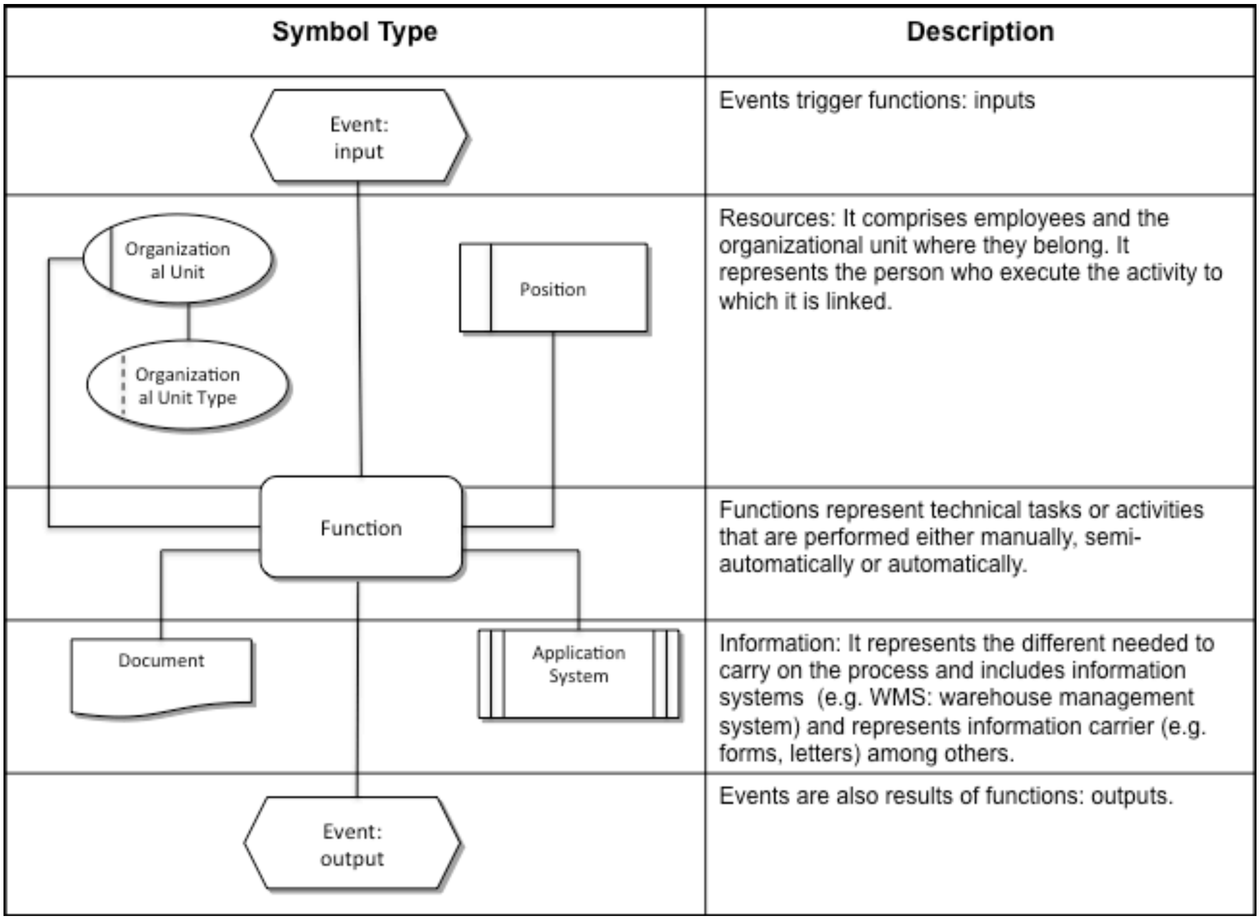

Figure 3-5 Symbolism in process mapping

Source: Aris Toolset from IDS Scheers.

Business process redesign

According to Hammer and Champy (1993), business process redesign (BRP) involves "the fundamental rethinking and radical design of business processes to achieve dramatic improvement in critical, contemporary measures of performance such as cost, quality, service and speed." BPR is inherently associated with change since it "implies radical departure from existing practices" (Fiedler et al., 1995); thus, it corresponds to a process-based approach to organizational change (Ramirez et al., 2010).

Information technologies are considered to be at the core of business process redesign as their adoption and integration bring about significant improvement on business processes (Davenport, 1993; Hammer and Champy, 1993; Fiedler et al., 1995; Ramirez et al., 2010). Davenport (1993) substantiate such believe by stating that 'by virtue of its power and popularity, no single business resource is better positioned than information technology to bring about radical improvement in business processes'. BPR is considered a mean to leverage the capabilities of IT, to change existing practices and to bring improvements with respect to organizational effectiveness and efficiency (Fiedler et al, 1995). However, the business value of IT implementation is not always easy to evaluate. The literature suggested that IT value should be evaluated taking into account the business processes that are impacted and (or) are enabled by the information technology to be adopted (Davenport and Short, 1990 in van der Heijden, 2002). Furthermore, the success of BRP projects has been questioned, as they do not necessarily bring about the expected benefits (Ramirez et al., 2010, Al-Mashari and Zairi, 1999, Hammer and Champy, 1993).

3.4 The thesis articles and subsequent thesis structure

The three thesis articles are presented below:

ARTICLE 1: Castro, Linda (2009). RFID Potential to Improve Asset Management of Mobile Equipment in Hospitals: Preliminary Results from a Field Study. International Journal of Automated Identification Technology, Vol. 1, No. 1, pp. 45-59.

ARTICLE 2: Lefebvre, E., Castro, Linda, Lefebvre, L.A. (2011) Assessing the prevailing implementation issues of RFID in healthcare: A five-phase implementation model. International Journal of Computers and Communications, Vol. 5, No. 2, pp. 101-117.

ARTICLE 3: Lefebvre, E., Castro, Linda, Lefebvre, L.A. (2013) Adding Intelligence to Mobile Asset Management in Hospitals: The True Value of RFID. Journal of Medical Systems, submitted.

As the three thesis articles investigate RFID implementation, it seems necessary to establish the link between each article, the research propositions and the implementation stages as previously proposed in the literature (Ngai et al., 2010). All seven implementation stages from the Ngai and co-authors' model are addressed in this thesis (Figure 3-6). However, research efforts for the last stage, namely continuous improvement, remained limited due to time constraints: After 25 months spent on data collection, the participants jointly decided in a wrap-up meeting to stop the research.

Data analyses were performed during and after the 25 month period, generating several refereed articles (visible research outputs). However, no attempt was made to draw together the overall results. This is precisely one of the goals of chapter 7 (Figure 3-6).

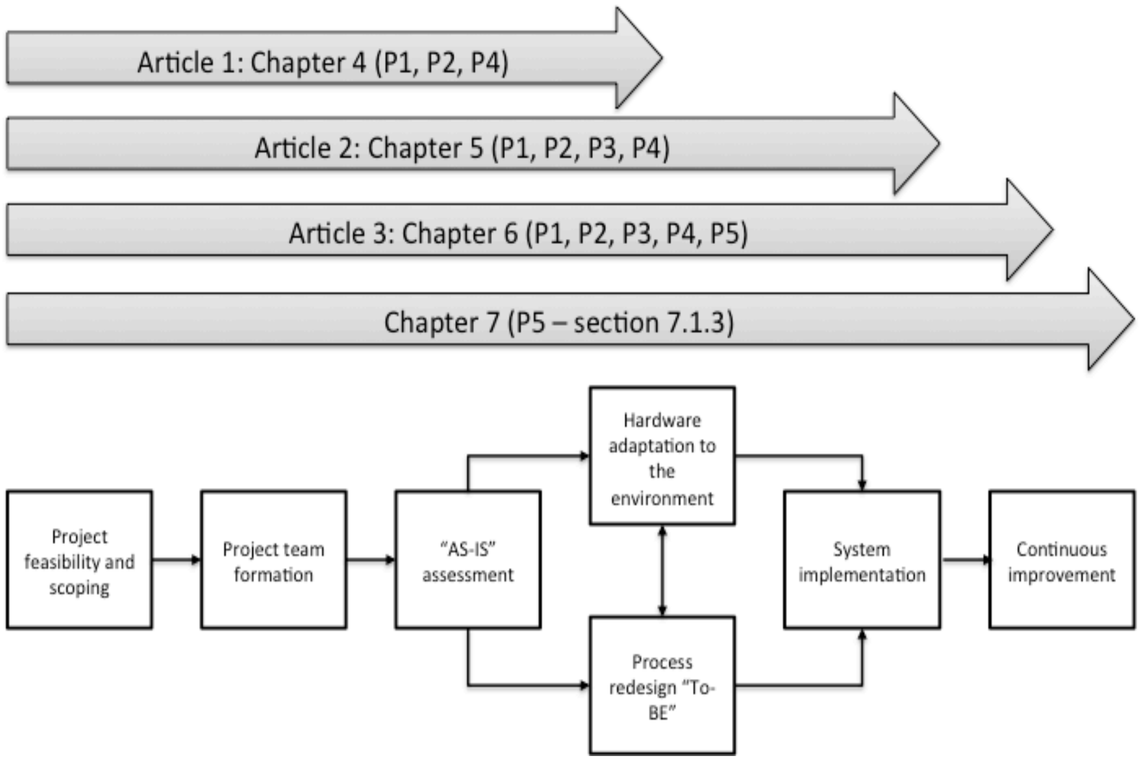

Figure 3-6 The structure of the thesis and the stages of RFID implementation model

The next chapters (chapters 4, 5, and 6) correspond to the three thesis articles.

CHAPITRE 4 RFID POTENTIAL TO IMPROVE ASSET MANAGEMENT OF MOBILE EQUIPMENT IN HOSPITALS: PRELIMINARY RESULTS FROM A FIELD STUDY[1]

Abstract:

In the healthcare sector, radio frequency identification (RFID) technology offers the potential to increase the performance of operations, enhance patient care, further system transparency, decrease costs and optimize asset utilization. This paper presents the early phases of the implementation of an RFID-enabled mobile asset tracking system in one hospital. From the preliminary results obtained in a real life context, this system allows to improve visibility and management of critical mobile assets, to eliminate non-value added activities and to generate intelligent processes, contributing to the overall improvement of operations within the healthcare facility.

Keywords: *Healthcare Industry; RFID; mobile asset management, asset visibility.*

4.1 Introduction

Mobile medical equipment ranging from infusion pumps, surgical equipment, hospital beds, blood supplies, portable x-ray machines, to wheelchairs constitute essential resources for assisting healthcare delivery and providing timely care to patients (Britton, 2007). However, tracking mobile assets represents a highly time consuming activity and the inability to find them when needed is remarkably costly and possibly life threatening. Hospitals, even small ones, handle on a daily basis several thousands of assets for which availability have to be ensured when needed to treat a patient. Mobile medical assets are constantly misplaced as they rotate

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[1] Castro, Linda (2009). RFID Potential to Improve Asset Management of Mobile Equipment in Hospitals: Preliminary Results from a Field Study. International Journal of Automated Identification Technology, Vol. 1, No. 1, pp. 45-59.

around various clinical wards in hospitals causing numerous problems. Ineffective asset management practices have resulted in shortages of life-saving equipment, burdens on clinical and technical staff, increases of operation costs, frustrations of hospital staff, and more importantly decreases in patient care. Studies have demonstrated that medical and non-medical staff are not able to locate 15-20% of their assets at any given time, that 10% of hospital inventories in capital equipment are lost or stolen every year, and that hospitals over-purchase equipment and supplies by 20 to 30% to compensate for stolen or lost assets, thereby increasing costs of inventory. Furthermore, nurses spend up to 30% of their working time seeking for the specific equipment they need and doctors spend an estimated 90 minutes per day searching for medical devices essential to execute their work: this is valuable time that should be dedicated to patient care (Aguado et al., 2007; Franklin, 2007; IDTechEx, 2007; Silicon, 2007; Aberdeen Group, 2006).

RFID (Radio Frequency Identification) technology has been identified as “the next evolutionary step in Automatic Identification Data Capture (AIDC) technology” (Lu et al, 2006). With much and recent adoption by large retailers such as Wal-Mart and by governments such as the US Department of Defence, the RFID applications are multiplying, driving the costs of these systems downwards and leading to further adoption. In some cases, RFID is mandated by governmental agencies. For instance, the US Food and Drug Administration is actively encouraging pharmaceutical manufacturers, distributors and retailers to use RFID to prevent drug counterfeiting. Consumer applications are already used in a variety of transportation-related contexts. RFID business applications are numerous ranging from asset tracking, food traceability, fleet maintenance, warehouse management and supply chain management (Lefebvre et al., 2005). RFID is evolving to become commonly used whenever access control and tracking of physical objects is required (Finkenzeller, 2000). In particular, RFID-based tracking solutions offer many potential opportunities to tackle problems related to locating mobile equipment 24/7 year-round in a hospital (Britton, 2007).

Various authors consider healthcare as an emerging niche for RFID and “the next home for RFID” (Schuerenberg, 2008; Di Giacomo and Bocchi, 2007; Tzeng et al., 2007; IDTechEx, 2006; Wang et al. 2006). In addition, healthcare organizations, government and IT solution providers have teamed up to assess through various RFID pilot studies the potential of this technology to track medical devices, medications, medical staff, and patients, as well as to promote continuous improvement of healthcare operations. For instance, an RFID-based blood transfusions tracking system ensures the traceability of the blood units administered to patients, promotes effective quality assurance and allows meeting patient safety requirements (Di Giacomo and Bocchi, 2007). Liao et al. (2006) describe an empirical case study on how a hospital in Taiwan developed a location system to build up a patient safety healthcare environment with RFID technology. From the study, they realize that RFID can promote medical process visibility and reduce the rate of medical errors. In the same line of thought, Thuemmler et al. (2007) present a passive RFID-based patient safety system designed to reduce errors in patient care. Kuo et al. (2007) also reveal that RFID integration can promote information visibility in emergency rooms. Janz et al. (2005) report on result from a "proof of application" and outline that RFID can support the measurement and control of workflow processes in hospitals and provide timely business intelligence for the healthcare optimistically impacting the quality of care delivered. Franklin (2007) presents a best practice model developed for the implementation of RFID in healthcare settings.

This paper focuses on the opportunities of RFID-based asset tracking systems to promote more efficient asset management activities in hospitals. This paper is structured as follows: the next section briefly introduces RFID technology and Real Time Locations Systems, describes the current context of the healthcare industry and evaluates various RFID applications for the healthcare industry. Section 3 presents the research design and describes the proof of concept. In section 4, the paper offers some insights of a field study focusing on the deployment of an RFID-based solution for asset management in one hospital while section 5 offers some concluding remarks.

4.2 Technological and contextual issues

4.2.1 RFID technology

RFID is "one of the most pervasive computing technologies in history" (Roberts, 2006). RFID uses radio signals to automatically identify and track products, medical devices, medical records, as well as individuals in hospital settings. RFID is progressively being perceived as an emerging technology that has the capabilities to improve care (Schuerenberg, 2008). According to Tzeng et al (2007), RFID may significantly transform an organization's capability to get timely information about the location and properties of RFID-enabled objects and individuals since this "intelligent object" become a mobile communicating element of “the organization’s overall information infrastructure” with the potential of triggering business processes automatically (Lefebvre et al., 2005; Curtin et al., 2007).

An RFID system is composed of three main components, namely (i) a tag or transponder, containing a chip and an antenna, which is placed in the physical object, (ii) a reader and its antennas that communicate with the transponder wirelessly and (iii) a host server equipment including a middleware.

RFID tags

RFID tags store unique product-item and individual’s information, including their physical location, serial number and expiration date. Information transmitted to a RFID reader can be stored in a database or used by organization’s staff (www.hibcc.org). RFID tags could be passive or active. Passive tags are not equipped with a power source and therefore need to be within the RF field in order to transmit their signal (Moen and Jellen, 2007). On the other hand, active tags are self-powered by a battery and therefore have greater communication range, superior data transmission rates, and larger data storage capacity compare to passive tags (Castro and Fosso Wamba, 2007). Passive tags are used for pallet tracking in retail supply chain, while active tags are used to track valuable assets. However, the price of RFID tags is still high and therefore massive adoption has not been reached yet. According to Huber et al. (2007) the price of an RFID tag follows the law of economies of scale, therefore as they will be produced on a broader scale, the price starts to drop which in turn favors a wider adoption.

RFID readers and antennas

RFID readers are devices that emit and receive radio signals activating RFID tags and capturing the data stored in them. Through their antennas, readers are able to both read data from and write data to tags (Li et al., 2006). Readers are responsible for information retrieval and acquisition, and therefore allow the information flows between the tags and the host system via the RFID middleware. Furthermore, they are able to identify and read without any problem a great number of tags per second. Depending on the carrier frequency and the type of tags, readers range could vary from a few centimeters to a few meters (Attaran, 2007).

RFID middleware

The RFID middleware corresponds to a set of software components serving as a bridge between the RFID tags and readers and the enterprise applications including warehouse management system (WMS), manufacturing execution systems (MES) etc. The RFID middleware is responsible for filtering and processing all information gathered through readers. Moreover, it be used to monitor and manage RFID readers' infrastructure (Liard, 2004; Sandip, 2005).

4.2.1.1 RFID-based location systems

RFID continues to evolve as new applications have emerged such as the RFID and WiFi based Real Time Location Systems (RTLS). RTLS deployments in hospitals include RFID-based wireless systems in order to locate and track patients, medical staff and valuable medical devices inside and outside hospitals (Jones et al 2007; Moen and Jelle, 2007). The implementation of Wi-Fi networks across hospitals is still controversial mainly due to possible interferences of wireless network with the medical devices (Di Giacomo and Bocchi, 2007). Wi-Fi-based RFID active tags transmitting in the IEEE 802.11 standards can be attached to physical objects and provide visibility since as objects move within a facility they are identified and located using standard Wi-Fi access points. Indoor positioning systems may be divided into three main categories: i) systems using specialized infrastructure, different from other wireless data communication networks, ii) systems based on wireless communication networks, using the same infrastructure and signals in order to obtain the location information, and iii) mixed system, that use both wireless networks signals and another sources to achieve the goal (Coca and Popa, 2007). RTLS used to monitor the location of assets and personnel within a facility in real-time is an uprising application for RFID. A recent study by Frost & Sullivan shows that the worldwide market for these systems is expected to grow to $1.26 billion by 2011 (Bacheldor, 2006).

4.2.2 Current context of the healthcare industry

The health sector represents the largest segment of the world economy (OECD, 2007) and is recognized as an important component of human welfare, as well as an essential driver for community-services infrastructure in our society (Banks et al, 2007; Lee, 2006). In the U.S. alone, healthcare represented 13.5 million jobs (including wage and salary workers) and approximately 411,000 jobs for the self-employed in 2004 (U.S. Department of Labor, 2005). Healthcare is a very complex system which faces remarkable pressures to cut down expenditures, enhance patient safety and client satisfaction, improve quality and reliability of services while maintaining a reliable year-round service (Fillingham, 2007; PWC, 2005a; Glouberman and Mintzberg, 2001). However, ineffective medical supply management, multiple proprietary systems and lack of technology standards have led to a rise of operational costs and a decrease of care quality, resulting in long waiting times, inefficiencies and discontented patients among others (Purbey et al., 2007; Aventyn, 2005).

Healthcare costs around the globe have attained unparalleled heights creating concern among healthcare providers (The Conference Board, 2006; Kumar et al., 2005). The collective healthcare cost of 24 OECD countries was $2.7 trillion in 2002 and health expenditures show a similar upward trend in the upcoming years (Figure 4-1). The HealthCast 2020 survey conducted by PriceWaterhouseCoopers among almost 600 hospital stakeholders (including executives of hospitals, physician groups, governments and medical supply companies) revealed that nearly half of healthcare executives consider that health spending will rise at a higher rate in the future. Indeed, healthcare spending is expected to reach $10 trillion by the year 2020, representing 21% of GDP in the U.S. and 16% of GDP in other OECD countries (PriceWaterhouseCoopers, 2005b). As a result, the healthcare sector in countries all over the world is under strict budget constraints.

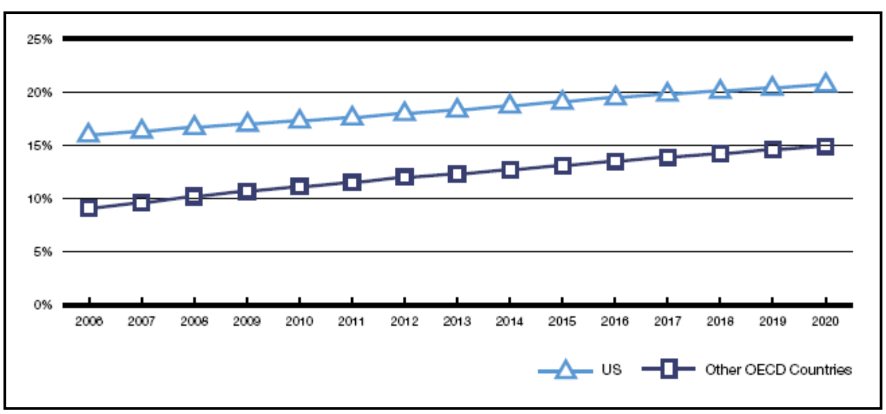

Figure 4-1 Estimated Health Spending for OECD countries as Percent of GDP (Source: PriceWaterhouseCoopers, 2005b)

Although the healthcare sector has been traditionally slow to embrace new business techniques and technologies (Wickramasinghe et al, 2005), it is now the time to evaluate opportunities proposed by emergent information technologies in order to reduce costs while facilitating healthcare delivery in order to offer patients with highly reliable care service. Respondents to the HealthCast 2020 survey found information technology (IT) as an enabler in resolving healthcare problems, with a majority of respondents believing that IT is important or very important to integrate care and improve information sharing, improve patient safety and restore patient trust (PriceWaterhouseCoopers, 2005b). In an effort to overcome these challenges and become a more agile and flexible system, healthcare organizations are moving towards the adoption of various health information technologies (e.g. EMR, CPOE) and other technologies since emergent information technologies such as RFID provide hospitals the means to measure and control their resources and workflow processes, resulting in a more reliable care service (Janz et al., 2005).

4.2.3 RFID potential to leverage healthcare operations

RFID potential to improve healthcare operations has expanded promoting interest among healthcare organizations, technology vendors, as well as governments. In the healthcare context, RFID technology offers the potential to increase the performance of operations, enhance patient care, further system transparency, decrease cost and improve asset utilization (Franklin, 2007). RFID adoptions in this sector are mostly focused on patient safety improvement, asset management and pharmaceutical supply chain visibility, patient medication management, blood supply management. Results from a survey carried out by BearingPoint and The National Alliance for Health Information Technology demonstrate that more than half of respondents from healthcare organizations have investigated RFID and about 10 percent have implemented the technology within their organization. Furthermore, within the next 24 months a remarkable 65% of respondents are expected to have deployed RFID (Figure 4-2). Remarkably, participants to the survey pointed medical equipment tracking as the number one RFID application they look forward to use within the next 24 months.

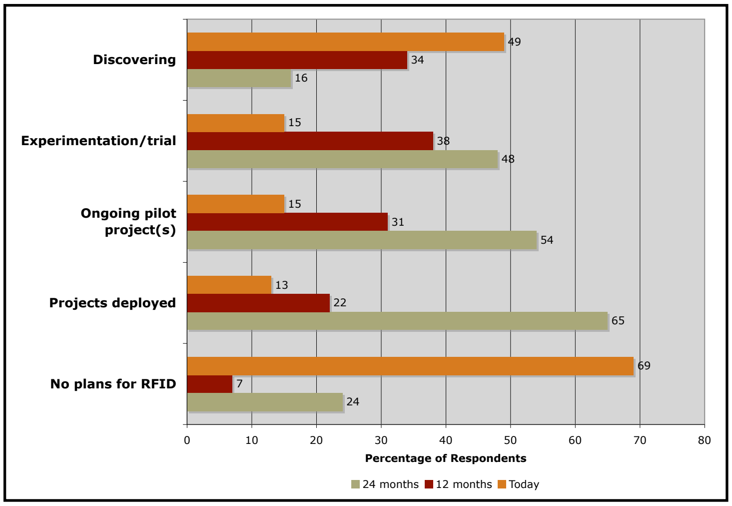

Figure 4-2 Trends for RFID Adoption in Healthcare (Source: BearingPoint, 2006)

Asset management

Among the different alternatives to cut down expenditures, the improvement of asset management within different healthcare organizations appears to be a worthwhile undertaking and RFID seems to be a viable alternative since this technology proposes key benefits to enhance the quality, efficiency and reliability of operations in the healthcare industry. The issue of managing and tracking valuable equipment and devices has been a great concern for healthcare organizations globally. In the present day, companies are encountering rising concerns in asset management context mainly due to the fact that products and materials are not managed individually. Moreover, information about location is not available, and information on status and usage is not accurate or lacking (Lampe and Strassner, 2005). The time wasted looking for assets lowers productivity, and consequently affects profitability. Indeed, workers lose the equivalent of one full 40-hour workweek per year if they take 10 minutes per day to search for needed items (Zebra technologies, 2003).

Experts perceive RFID as the enabling technology that empowers and improves asset management and believe that RFID is the number one reason among diverse industries, including healthcare, to undertake an RFID implementation (Belkin, 2006). RFID technology facilitates the seamless tracking of medical equipment and devices in hospitals making possible to locate and identify them in real-time while preventing shrinkages. Further, RFID seems particularly relevant for asset management since it allows "value-added applications related to the tracking and intelligent management of any object tagged with an RFID chip", as well as the automation of the labor-intensive assets roundup (Janz et al., 2005; Lee et al., 2007).

Patient safety

Patient safety is the most crucial issue for healthcare organizations (BearingPoint, 2006), however, over 98,000 deaths occur in the U.S. every year due to preventable medical related errors, of which 58 percent may have been averted (BearingPoint, 2006; Institute of Medicine, 2000 and 2001; Aventyn, 2005). Tanner (2002) traced 40 potentially injurious drug errors occurring daily at hospitals in the U.S. The precise management of medications administrated to patients thus represents a top priority. RFID bears the capabilities to enable a seamless and accurate identification of patients in order to eliminate medication administration errors by ensuring the five rights of medication administration: i) right patient, ii) right drug, iii) right dose, iv) right route and v) right time (BearingPoint, 2006). Accurate drug administration, patient's status follow up and elimination of patient's identity mix-up are some of the benefits that RFID technology can offer regarding patient safety (Alvin Systems, 2005).

Patients could be provided with a RFID-enabled wrist-band as soon as they admitted to the hospital in order to comply with patient safety requirements. Patient's RFID wrist-bands could be easily read with RFID-enabled devices (e.g. PDA, Tablet PC). As a result, every time a medical procedure should be performed on a patient or a medication should be administrated, medical staff would be able to instantly and uniquely identify each patient and get access to their health records information such as allergic reactions, prescribed medications, medication's dosage, blood type and lab results. There are some ongoing pilots to test the capabilities of RFID in this area. For instance, the Jena University Hospital in Germany is deploying a RFID pilot to track medication from the pharmacy to the patient to ensure patients get the right amount of the right drugs (Wessel, 2007). Also, the Chang-Gung Hospital in Taiwan is using RFID-enabled passive wristbands to identify surgical patients and track their operations to improve patient care and safety. This system allows medical staff to save an average of 4.3 minutes per patient when performing patient identification and authentication processes (Bacheldor, 2007a).

A study conducted by the National Patient Safety Agency in 28 acute NHS organizations reveals that: i) 44 patient-safety incidents linked to an erroneous procedure, site or patient name and notes, among others, occurred between September 2001 and June 2002 and that ii) 15 patient-safety episodes associated to surgery at the incorrect side were identified between November 2002 and April 2003 (Bacheldor, 2007b). There have been some initiatives to use RFID as an enabler to retrieve the appropriate patient record, including the planned procedure. For instance, in the U.K. the Birmingham Heartlands Hospital is implementing a system using passive high frequency (HF) RFID-enabled wristbands to track patients and procedures in two surgical wards to improve patient safety by ensuring that all patients receive the appropriate surgical procedure (Bacheldor, 2007b). Additionally, RFID could be also used to track and locate mentally afflicted patients (e.g. patients diagnosed with Alzheimer's disease), identify newborn babies to avoid child's abduction and mother-baby mismatchings (Aguado et al., 2007), and track the historical movement of patients to restrict contact with contagious disease outbreaks such as SARS (Wang et al. 2006).

4.3 Methodology

4.3.1 Research strategy

Compared to other industries, healthcare organizations are adopting RFID at a slower pace (Chao et al., 2007) and therefore there is a paucity of research contributions concentrating on RFID adoption and implementation within the healthcare (Tzeng et al, 2007; Wicks et al., 2006). The lack of studies on how RFID should be implemented in hospital settings constitutes a key starting point and a chief motivation for this research. Moreover, the case-study strategy appears to be the most appropriate to study the implementation of innovation in the hospital settings, particularly, when analyzing an "emerging phenomenon" about which "little" is known (Cosmi, 2005; Yin, 2003). The fact that the proposed research evaluates an emergent technology within a context (hospitals) where research studies are limited is definitively an influential factor to decide on conducting a "detailed longitudinal exploratory case study".

Field research was conducted in five consecutive phases as shown in Figure 4-3.

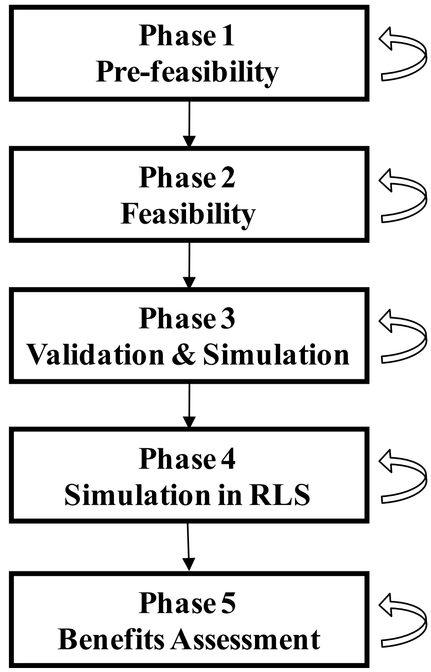

Figure 4-3 Phases of field research

The initial phase or pre-feasibility corresponds to the development of strategic alliances with technological and industrial partners for selected RFID-based asset management applications. During this stage, the main ideas and concepts were first tested, receptivity and interest from all partners involved were assessed, and preliminary commitments were evaluated, among others. Moreover, the preliminary mapping of actual processes related to one specific asset was performed. The "as is" processes were designed using the software Aris Toolset from IDS Scheer.

Opportunities were then investigated in the "feasibility phase" which was conducted between March 2007 and September 2007. In order to better understand the context of asset management activities within the hospital settings and determine the scope of the project, answers to the different questions were sought, such as: What are the critical asset management activities in terms of medical equipment? Which activities are within the scope of the project? What types of assets are critical for the different professional groups? Which entities within the organization will participate in the project? Furthermore, this phase allowed answering several critical questions regarding RFID technologies integration, such as: How would the technology really work? Is the technology compatible with legacy systems? Would the technology generate interference with other equipment? How will the data be collected? During this phase, a RF finger printing of specific areas in the hospital was undertaken using a Rohde & Schwarz FSH6 spectrum analyzer in order to measure possible interference and Wi-Fi coverage.

The third phase "simulation and validation" aimed at evaluating the potential of RFID within the context of asset management activities while concerns related to business and technological issues were assessed. It included the elaboration of different technological scenarios leveraging on existing legacy systems and technology. These scenarios integrating RFID technology were then thoroughly evaluated in order to select the "retained" scenario.

During the "the proof of concept" phase, the RFID scenario retained in the previous phase was implemented in a real life setting while the impacts and challenges related to RFID adoption were evaluated. "Benefits assessment" corresponded to the fifth and final phase.

4.3.2 The observation site

This study is taking place in one hospital in the Netherlands (hereinafter referred to as *"NL Hospital*"), which corresponds to the site for deploying the RFID-based mobile asset tracking system and evaluating its value. The *NL Hospital* is a modern general hospital with approximately 180 medical specialists and almost 30 medical units. The hospital relies on various enterprise applications, including a maintenance management system (MMS), as well as a warehouse management system (WMS) In order to manage and monitor assets inventory, maintenance and repair, the *NL Hospital* uses a barcode system which requires manual intervention and a line of sight. Furthermore, this type of system is static and only provides asset visibility when barcodes placed on the assets are scanned either when assigned to a medical unit or when returned to the central storage room. Moreover, in an effort to become more digital, *NL Hospital* has implemented a Wi-Fi network and has implemented a telemetric system across its facilities for patient monitoring (critical patient heart beats and other conditions are being monitored). Nearly 100% of the hospital is Wi-Fi enabled.

4.3.3 Data collection methods

In order to evaluate the impact and challenges of implementing RFID within hospital settings, a number of information sources were used so that they could be triangulated, including: i) focus groups; (ii) multiple onsite observations iii) semi-structured interviews, iv) unobtrusive data collection, and v) other sources.

Focus groups were carried out in one university-based research center and at the hospital. Key managers and IT experts reached a consensus on the strategic intents with respect to the use of RFID, evaluated different scenarios scenario and selected the 'retained' scenario.

Several on-site observations were conducted in order to carry out the mapping of the actual business processes "AS IS". Onsite observations were conducted at different periods during the year 2007.

Semi-structured interviews allowed to collect the detailed information that was necessary for the mapping of existing processes related to one specific asset, from the time it is received from the manufacturer at the NL hospital through its usage and maintenance/repair activities. Key respondents from various departments/units at the NL hospital have participated to the interviews, namely the personnel from medical-technical department (e.g. managers, technician), from various medical units (e.g. team managers, head nurses), from the ICT department (e.g. manager of automation) and from storage room (e.g. clerks). Most of the interviews were recorded, since some participants accepted voice recording.

We also relied on unobtrusive data collection methods which involved the collection and continuous analysis of the data generated by RFID tags and the corresponding information from the middleware. The collection of this data started in December 2007 and ran until April 2008.

In order to better understand the context and challenges of an RFID implementation within the NL hospital, other sources of information were used such as internal reports and other corporate documents, Internet-based information on the hospital, and other publicly accessible information (e.g. academic articles).

4.4 Findings and discussion

In the scope of this paper, we will present and discuss the empirical results obtained in pre-feasibility, feasibility, simulation and validation phases as discussed in section 3.1. More specifically, we will center the discussion on some specific processes, namely the 'picking and transfer of equipment process' at the central storage room and the 'usage or request for equipment process' in two medical units.

4.4.1 Motivations and selection of one type of assets

Key managers from the *NL Hospital* indicated that their deepest concerns in terms of asset management are the lack of real-time information regarding key medical equipment. They therefore wanted to evaluate how RFID could improve the information flow and management of strategic medical equipment across the organization while also delivering economic benefits. Given that there was no visibility of equipment's location at the hospital, it was also a problem for the staff in the central storage room to comply with medical unit's demand for equipment. When equipment was not available when needed, it directly affected the quality of medical care to patients.

During the pre-feasibility phase, the decision of restricting the RFID implementation to one type of mobile medical equipment, namely "the infusion pumps" was taken. Table 4-1 summarizes the primary motivations leading to the selection of infusion pumps. It is evident that these motivations are centered on operational inefficiencies, cost reductions and improvement of care quality.

Table 4-1 Motivations for selecting infusion pumps for the proof of concept

Inefficiencies as perceived by respondents	*Details*
Shortage of available equipment	There is recurrently a shortage of infusion pumps in central storage room, resulting in constant complaints and frustration from nurses and doctors. In various occasions during the field study, it was noticed that the designated shelf for infusion pumps was totally empty.
Cost of equipment	Infusion pumps are expensive equipment, costing about € 1,500 each. Replacement and overbuying are costly for the hospital.
Quality of medical care	Missing one infusion pump could critically affect patient care.
Shrinkage	Over the last few years, about 30 pumps were lost, representing 25 percent shrinkage rate.
Lack of visibility	Although the hospital identifies each pump with a bar code label, it is not possible to locate infusion pumps as they rotate between medical units. Once, the pump leaves the storage room, the visibility is basically lost.
Lack of visibility during specific shifts	During nights, weekends and holidays, the head nurse is responsible for equipment allocation. The head nurse is supposed to register all equipment exits from storage room in a paper-based system but the information is seldom registered. Hence, storage room clerks do not have visibility of equipment removed during these shifts.
Risk of failure	Infusion pumps are considered as "high-risk" medical equipment in terms of the level of thread any failure could represent to a patient's health.
Equipment misplacement	Each ward looks for best interest of its own patients. After usage, nurses do not return infusion pumps to storage room. Nurses believe that if they give up a pump, they likely will never see it again; thus they hide them (e.g. in closets) so that they will have one available next time they need one.
Time waste	Locating an available pump is time consuming for storage room clerks, as well as for nurses and in some occasions it could take up to one hour to find an infusion pump.
Failure to meet maintenance	Maintenance staff is not able to promptly locate infusion pumps in order to perform a recall or a scheduled maintenance, which could potentially lead to patient's harm.

4.4.2 The retained scenario and proof of concept

The retained scenario corresponds to a RFID Wi-Fi-based real-time location system to track infusion pumps throughout two medical wards, hereinafter referred to as *Ward A* and *Ward B*, and the central storage room of the *NL Hospital.* In these two wards, the availability of infusion pumps is critical. *Ward A* has 35 beds and receives about 2 to 3 planned patients on daily basis, plus any emergency patient, while *Ward B* has 40 beds and admits some 8 to10 planned patients per day or about 40-50 per week, plus any emergency patient. At *Ward A,* infusion pumps are really necessary since approximately 90% of patients admitted need to be administrated numerous medications at the same time for up to 7 days. However, according to hospital statistics, out of the 90% of patients who require the use of an infusion pump only 80% get one. On the other hand, at *Ward B*, out of an average of 50 patients per week, 30 patients (60% of 50 patients) will need a pump, still only 20 patients (40% out of 50) will be assigned one. Team leaders from both wards agreed that information about availability of this critical medical equipment is essential. More specifically, they would like to know how many pumps are available for the use of their units at any given time.

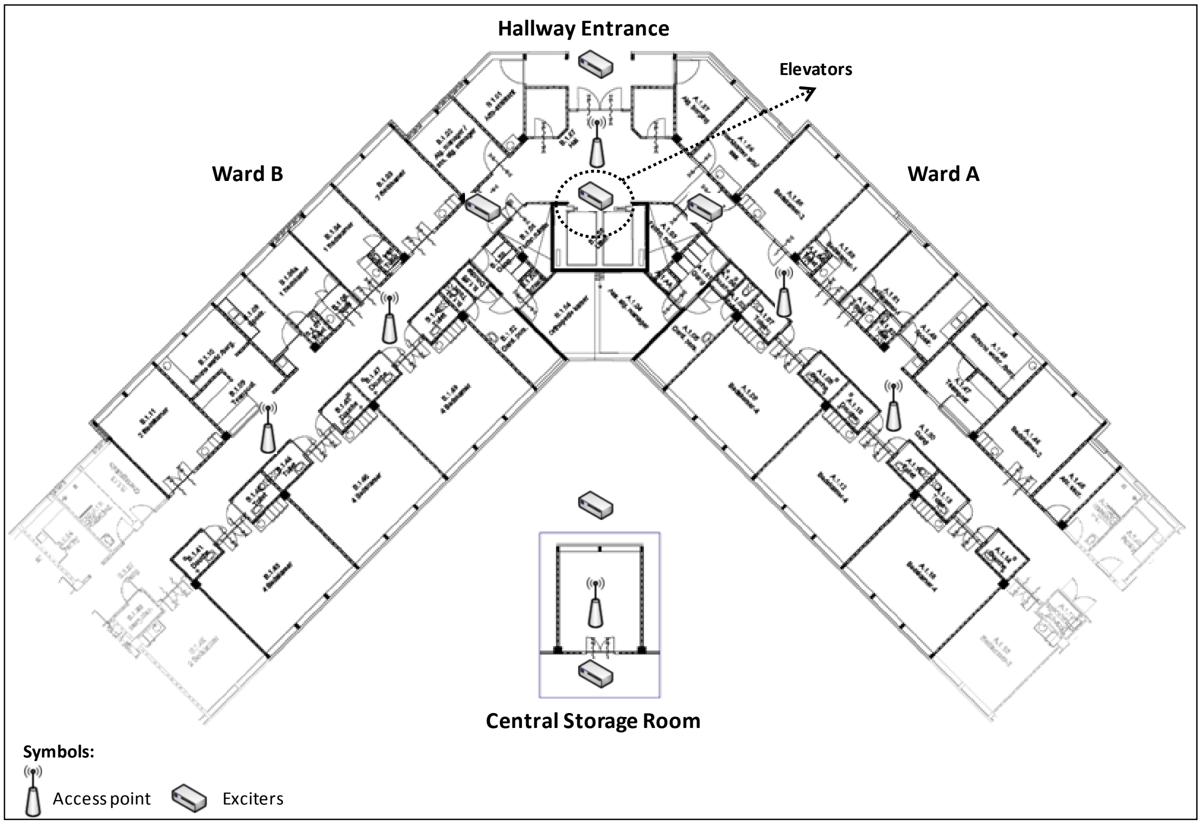

Figure 4-4. Layout of proof of concept zone

4.4.3 RFID-based mobile asset tracking system configuration

In order to leverage the legacy systems and technological infrastructure, the proposed RFID-enabled mobile asset tracking system runs on the *NL Hospital*'s existing Wi-Fi network. The proposed system consists of six Wi-Fi access points, six exciters, forty Wi-Fi-based RFID active tags broadcasting in the 802.11 standard, one tracking engine, as well as an enterprise tracking software. As depicted in figure 4-4, two access points are located in the corridor of each of the two wards, one access point is at the level of the common entrance of the two wards, and one access point is located at the central storage room. There is one exciter right at the entrance of each ward, in order to register any entrance or exit of equipment while two exciters are located respectively in front of the elevators and at the entrance hallway, which are the only two possible ways in/out the proof of concept zone. Finally, one exciter was installed at the entrance of the storage room to register entrance and exit of tagged equipment, and another exciter was placed next to the infusion pump's dedicated shelf in order to monitor the in-stock equipment. Active tags mounted on the infusion pumps are detected by exciters as they pass by their coverage area, which transmit tags ID numbers to wireless access points. This information is used by the tracking engine in order to determine tags location. Finally, the enterprise tracking software provides a layout plan of *Wards A* and *B* and of the storage room and displays real-time information on the exact location and status (in use, not in use) of the infusion pumps: the information is available to nurses, warehouse clerks, hospital managers, and maintenance staff.

4.4.4 Existing business processes

The field research entailed the mapping of business processes at different points in time. Following the proposed methodology (section 3.1), we started by mapping the "as is" business processes (figure 4-5). A process-based approach is considered as "a more dynamic description of how an organization acts" (Magal et al., 2001: 2). Moreover, this process view allows organizations to move away from traditional functional structures and to focus on value creation. It implies a strong emphasis on "how work is done within an organization" (Davenport, 1993, p 5). These processes are mapped using a drilled-down approach from the more general to the more detailed.

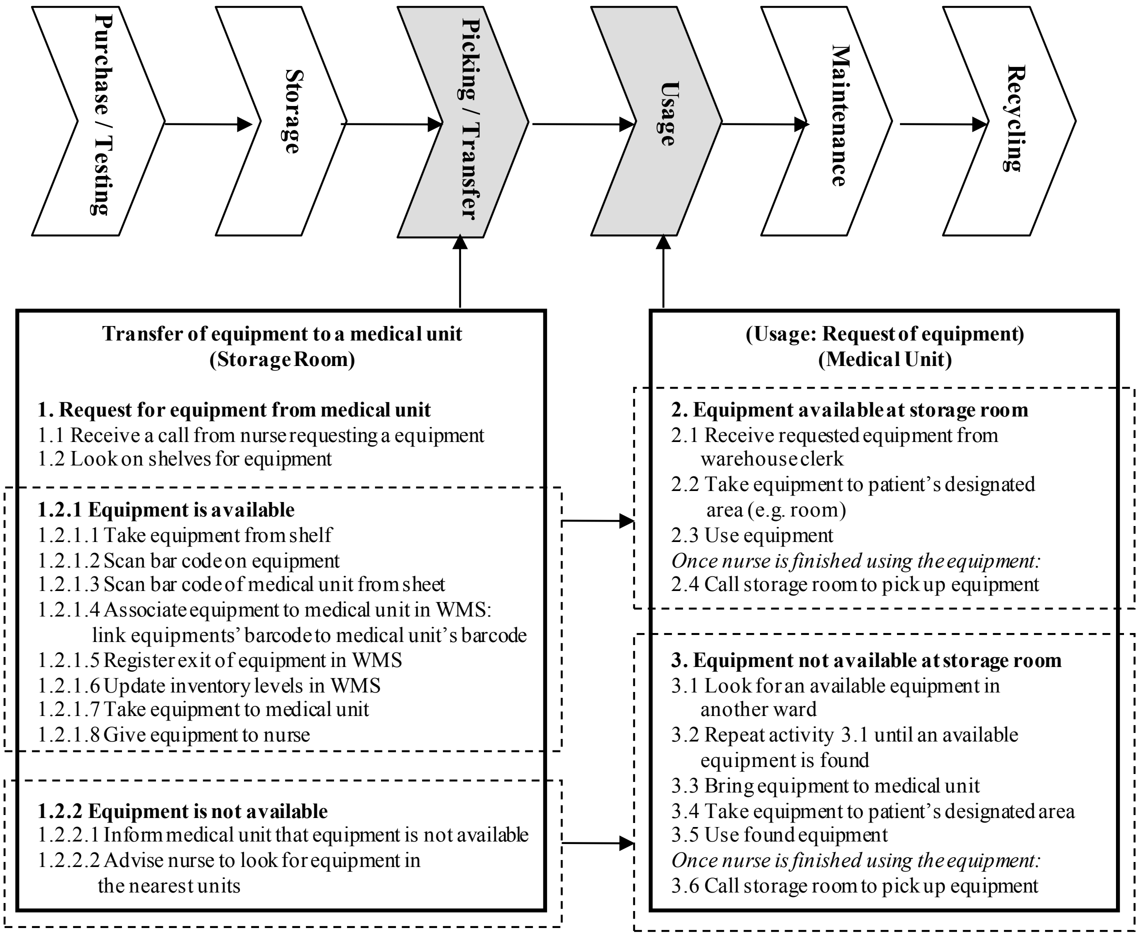

Figure 4-5. Existing Business Processes

Based on the analysis of the actual inter and intra unit processes, the following observations are made:

i) Today none of the processes are performed automatically. However, It exists a certain level of automation since some processes are performed semi-automatically (e.g. 1.2.1.4, 1.2.1.5 and 1.2.1.6, figure 4-5).

i) Since warehouse clerks do not have visibility of the location of individual equipment, clerks recommend nurses to look for needed equipment across different medical units, starting by the closest one to their unit (1.2.2.2, figure 4-5). Consequently, nurses have to search unit-by-unit for available equipment (e.g. 3.1 and 3.2, figure 4-5) which represents a time-consuming activity that distracts them from their direct function: 'give care to patients'. From the interviews carried out during the field research, it was found that in some cases it could take up to 1 hour to find an infusion pump (this represents the worst case scenario but applies only in the cases when a pump is actually found).

ii) Even though the *NL Hospital* keeps records of the exit of equipment from the storage room towards all medical units through the usage of the existing bar coding system (1.2.1.4 in the 'picking and transfer of equipment' process), there is no record of equipment transfers between medical units. On a daily basis, when equipment is not available at the storage room, nurses look for required equipment in different units. When they find one, they bring it to their own unit without reporting this inter-unit equipment transfer to the storage room. As a result the hospital loses all equipment visibility. During the field study, it was found that most of the time the storage room did not have in stock enough infusion pumps due to the lack of visibility of these assets that rotate within the hospital. After usage, nurses are supposed to call the storage room and report that they finished using the equipment (e.g. 2.4, Figure 4-5), then a warehouse clerk will come to the medical unit to recover it. However, in reality, returns of equipment to the storage room is not the nurses' priority and hence, nurses commonly misplace or hide equipment in order to ensure the availability of the devices for the next time.

4.4.5 Business processes integrating RFID technology

The selected RFID scenario as described in section 4.3 was systematically validated with the technological partners as well as with management staff from different units in the hospital. A gap analysis was undertaken in order to contrast the current situation (Figure 4-5) from the future situation integrating RFID technology (Figure 4-6). The gap analysis allows to evaluate the potential of RFID to improve the overall efficiency of operations related to asset management and to examine the potential impacts derived from RFID.

Figure 4-6 shows the reengineered business processes with the proposed RFID-enabled mobile asset tracking system. Even though the asset tracking system has been Implemented and is totally functional, it was decided by the *NL Hospital* management that during the proof of concept only the manager of the medical technical department, the university-based researchers and the technological partners have access to the information collected through the system for research purpose.

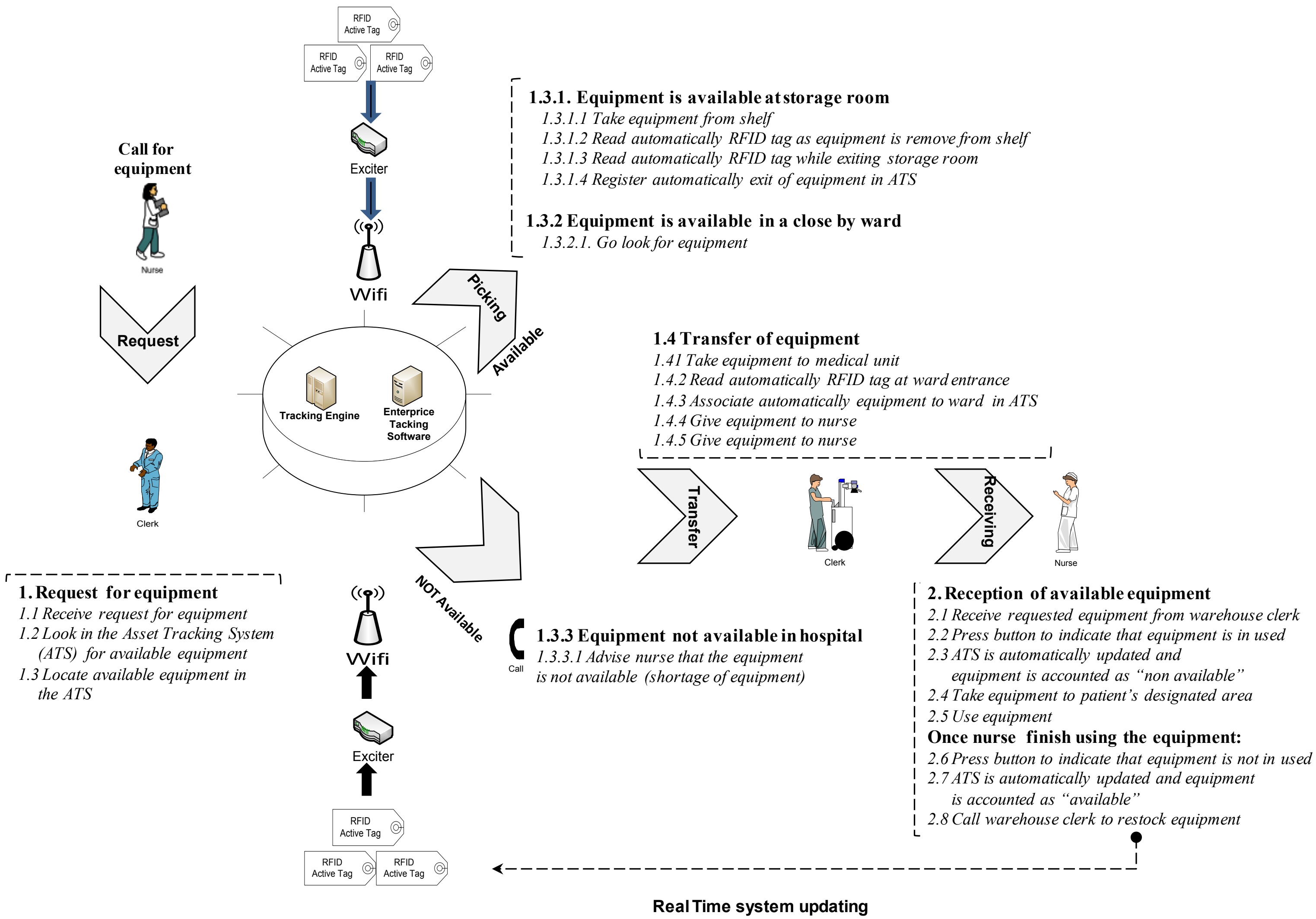

Figure 4-6 Business Processes integrating RFID

Preliminary results from the proof of concept reveal that the adoption of RFID technology has the potential to promote the improvement of asset visibility, the elimination of non-value added activities and the emergence of smart processes contributing to the overall improvement of operations within the healthcare facility.

Asset visibility

Asset visibility is considerably improved, as it allows real-time monitoring of mobile assets, including availability, utilization, status, localization. Access to real-time information about the medical assets will bring about a number of potential benefits for medical units, warehouse managers and staff, maintenance departments, and hospital managers.

With respect to the *medical units,* an increase in asset visibility implies the following direct and indirect benefits: i) equipment will be available when needed and where needed, therefore medical staff will be able to have access to needed equipment at all times, resulting in a higher quality of service delivery to patients; ii) medical staff will be able to know how many units of any equipment they have in their units at any given time, iii) medical staff will be able to response rapidly to emergencies and unpredicted critical events since they will have available the needed equipment; iv) levels of product availability are increased and therefore medical staff frustration will be greatly reduced; v) improvement in productivity and efficiency will occur by reducing the time the hospital staff spends in locating misplaced assets (e.g. process 3.1 in Figure 4-5). As shown in Figure 4-6, RFID integration decreases medical staff time to respond to patient health demands since equipment location is available in real-time.

For the *central storage room* there are also several possible benefits. For instance, storage room clerks would be able to access product location and availability information via the proposed RFID-enabled mobile asset tracking system when equipment is needed and therefore be able to comply with clinical requirements for equipment (e.g. process 1.2 and 1.3 in Figure 4-6). As the equipment rotates throughout the hospital, personnel will be able to have visibility on the exact location, since equipment will be *identified* and *associated* to a unit by the exciter located at each ward entrance (e.g. 1.4.2 and 1.4.3 in Figure 4-6), therefore, information concerning infusion pump flow and transfer from one unit to another will be automatically recorded in the system.

Table 4-2 Summary of data collected during proof of concept

Data from 15/12/07 to 01/04/08	Ward A	Ward B	Ward A&B	Other Ward	Total
Number of pumps used by Ward	*6*	*8*	*14*	*12*	*40*
*% of RFID-enabled pumps used by Ward**	*15%*	*20%*	*35%*	*30%*	*100%*
Total Pumps days by Ward	*461*	*739*	*1200*	*Not available*	*2400*
Number of pumps that returned to storage room	*6*	*5*	*7*	*3*	*21*
Total number of tag readings	*292*	*246*	*779*	*Not available*	*1317*

Table 4-2, summarizes some of the data gathered through the asset tracking system over a period of 109 days. From this table, we can notice that readings by the exciter located at the entrance of *Wards A* and *B* and storage room provide timely information of the movement of infusion pumps across the proof of concept zone. For instance, this table shows that 292 readings were recorded at *Ward A* entrance, which reports the movement of 6 RFID-enabled tags as they enter and exit *Ward A*. This high number of readings is due partly to the fact that patients using infusion pumps are allowed to walk across certain areas in the hospital and therefore may pass in many occasions in a daily basis under the exciter located and the entrance hall. Since medical staff does not return promptly to the storage room pumps that are not longer in use and opt for keeping them in their wards in order to have one available next time they need one, there is a very low rate of equipment returning to the storage room: Table 4-2 shows that from the 40 infusion pumps studied only 21 returned at some point to the storage room, therefore 48% of the RFID-enabled pump were never restocked during 109 days. Finally, information about equipment check outs from storage room during night/weekend/holidays shifts is currently lacking. but asset visibility during night shift will be achieved through the proposed RFID-enabled system. For instance, from the data collected from the system (Table 4-2), we can notice that the system is able to automatically register the exit of RFID-enabled pumps as they were leaving storage room at night, weekends or holidays since some readings were gathered after 7:00 pm.

From a *hospital management* perspective, better visibility of hospital assets will reduce overbuying and rental of additional equipment and eliminate costly replacement of lost or stolen equipment. As a result of the higher level of visibility, assets will be fully utilized. Table 4-2 reveals that 6 RFID-enabled pumps were at certain point used by *Ward* A and that they were never used by *Ward B*. Same case applies for *Ward B* were only 8 of these pumps were used within their medical unit and never used in *Ward A* showing clearly how some assets even they are mobile they do not have the same profile: some behave more like fixed assets, since they are repeatedly used in the same unit. However, 35% of the tagged pumps (or 14 pumps) were used by both *Ward A* and *Ward B* showing that other pumps behave more like mobile assets since they move frequently around different units in the hospital. Even though we have analyzed the same type of asset, it is interesting to see how there are some infusion pumps that will be more easy to find that others. This information seems to be of great relevance for asset managers since integration of RFID will promote visibility of equipment independently of their fixe or mobile profile.

Finally the *medical equipment maintenance staff* will be able to comply with maintenance standards, proceed with equipment recalls and conduct calibrations activities, thereby avoiding failure of equipment, since information concerning tagged equipment will be available and accessible. RFID has the capability to promote the improvement of communication and decisions by keeping up-to-date equipment maintenance related information such as maintenance history, schedule of maintenance, repairs.

Elimination of non-value added activities

Time-consuming activities including locating an available equipment across the hospital which can take up to one hour (e.g. 3.2 in 'usage', Figure 4-5) and manual scanning are now either eliminated (e.g. 1.2.1.2 and 1.2.1.3 in 'transfer of equipment', Figure 4-5) or performed automatically (e.g. 1.3.1.2, 1.3.1.3 and 1.3.1.4 in Figure 4-6) through the usage of Wi-Fi-based RFID active tags and a network of Wi-Fi access points. Therefore, the probability of human related errors could be significantly evaded. Moreover, diverse activities such as calling storage room to pick up equipment (process 2.4 and 3.6 in figure 4-5) will be eliminated since the system will provide information for all pumps that are available across hospitals wards. Clerks could verify at intervals pre-set by the RFID-enabled mobile asset tracking system the availability of infusion pumps and proceed to collect the available pumps for restocking in the storage room. Since clerks do not have yet access to the system, it is still necessary to call in order to demand equipment restocking (process 2.8, Figure 4-6). However, once the system will be fully deployed there will be no further need for this activity and therefore process 2.8 could be eliminated.

Emergence of intelligent processes

As per processes 2.6 and 2.7 (figure 4-6), medical staff could use call buttons integrated in the active RFID tags in order to report certain relevant events, such as the end of equipment usage. Alerts could be sent automatically to a dedicated employee, for instance the warehouse clerk would be informed (by an alert or by checking the system) that a specific equipment in not longer in use and therefore is ready to be restocked in the storage room. Other possible future applications could involve sending automatic notifications to the maintenance staff to notify that specific equipment is due for maintenance shortly.

4.5 Conclusion

RFID is anticipated to revolutionize a large number of industries, just as bar coding technology revolutionized the retail industry more than two decades ago. RFID is more than a technological hype as it has already reached a critical mass of adopters and has recently emerged as a strong candidate for more wide spread use in the healthcare sector, especially for asset management in hospital. Indeed, the current inefficiencies with respect to medical assets management and tracking in hospitals generate operational and economic challenges.

This paper has presented the early phases of the implementation of an RFID-enabled mobile asset tracking system in one hospital. From the preliminary results obtained in a real life context, RFID holds the potential to improve visibility and management of critical mobile assets, to eliminate non-value added activities and to generate intelligent processes. Adding intelligence to processes represents probably the most important and challenging area of improvements that could be derived from RFID technologies. The next steps of this research initiative will be directed towards the elaboration of decision rules that will draw upon the data generated by the system to further automate non-value added processes, thereby triggering “intelligent” processes.

It is expected that organizational issues may prevail over technological issues since a more widespread adoption and integration of the RFID-enabled mobile asset tracking system demand substantial process redesign, which in turn may lead to organizational changes. Early implications of key players, including IT solution providers, medical staff, healthcare trustees, researchers and others have proven to be a valuable strategy and their on-going implication and inputs will facilitate further adoption. Special attention should also be placed on a "scalable solution" since executives at the hospital would like to make the most of any future investment. In fact, the proposed RFID infrastructure for tracking infusion pumps shall be used for other critical mobile assets and other value-added applications such as patient and staff tracking and identification.

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CHAPITRE 5 ASSESSING THE PREVAILING IMPLEMENTATION ISSUES OF RFID IN HEALTHCARE: A FIVE-PHASE IMPLEMENTATION MODEL[2]

Abstract

In healthcare, supply and demand of medical devices and equipment pose enormous challenges for material managers who have to ensure that "the right equipment" is at "the right moment" at the "point-of-need". Every year hospitals lose millions of dollar due to hoarded, lost, stolen, and misplaced medical equipment. This lack of visibility on critical medical assets has led to increase of operations inefficiencies, increase in needed resources and budgets, loss of staff valuable time, as well as delays in patient care delivery, generating patients and staff dissatisfaction and potentially affecting patient flow and safety. Radio frequency identification (RFID) is rising as an enabling technology to facilitate asset management in healthcare, where caregivers continually use thousands of medical devices across multiple clinical departments. RFID proven capabilities to automatically and capture, share and synchronize product's information, as precise as at the item-level, is giving rise to new paradigms for the management of critical and life-saving medical equipment in hospitals. Even tough RFID seems to be a very promising technology; its adoption and implementation in this sector have been hindered by the haziness of RFID projects' ROI. Through a case study at a European hospital, we intend to assess the suitability of a proposed RFID implementation model to evaluate the various implications of RFID projects, the prevailing implementation issues, as well as to investigate the anticipated benefits of such implementation.

Keywords**:** *healthcare, mobile asset management, key performance indicators, RFID implementation.*

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5.1 INTRODUCTION

THE healthcare sector faces challenges like no other industrial sector, since any mistake, any system inefficiency could put in peril people's lives. Consequently, the number one priority of healthcare systems is to ensure prompt and safe care delivery to patients. In order to do so, they need to have access to necessary human, material, informational and financial resources at the point-of-care. However, management, synchronization and alignment of diverse flows necessary to effectively operate healthcare systems is very complex. Healthcare facilities, in developed as well as in developing countries, are continuously facing a multiplicity of challenges including medical errors, lack of necessary resources, inefficient workflows, inefficient information management, process disparities, as well as a disintegrated healthcare logistics; affecting patient safety and contributing to a rise in current spending. Healthcare is going through a dramatic transformation in order to respond to the demands of the new century and fight error in medicine. The future of healthcare seems very turbulent; hence, stakeholders in this industry are prompt to pursue suitable actions and integrate best practices into their operations to overcome the myriad of challenges increasingly faced by healthcare systems, become more efficient and improve medical outcomes.

Healthcare organizations (HCOs) could achieve substantial savings by learning from and embracing technological strategies undertaken by leaders in other industries [1, p.545]. In an effort to address the core mission of healthcare organizations and reduce the occurrence and impacts of medical errors, a more advanced use of information technology (IT) at clinical and managerial levels has been suggested [2], [3], [4], [5]. Enabling technologies are perceived as strategic assets could play a pivotal role to ensure continuity of care and quality of services delivered, increase patient safety, increase the efficiency of personnel, enhance customer service, reduce organization expenditures, preserve patients' trust, successfully attain organizational goals and objectives [4], [6]–[8].

In spite of the global widespread of IT integration in many vertical markets, healthcare has traditionally lagged behind other service industries when it comes to implementing innovative IT [5], [8]–[13]. However, the implementation of several IT applications, including applications for digitizing medical records and clinical data [13], have generated documented benefits, such as the reduction of operating costs, the improvement of operational efficiencies, the increased of productivity, the automation of processes, and elimination of waste and duplication [14].

During the last decade, governments have acted as important drivers for IT adoption through the promotion of several initiatives. For instance, the NHS Connecting for Health Agency in the UK has led the National Program for IT (NPfIT), which corresponds to most substantial IT investment in England [15]. According to Natarajan [10], the US federal government has played as well an essential role in the application of health information technology (HIT). Back in 2004, President George W. Bush pointed out the need for nationwide adoption of HIT within the next 10 years [16]. In the US alone, healthcare investments in IT could result in cost savings in the order of $140 billion a year by 2014 [17].

Innovations in the field of mobile technology are opening new opportunities to prevail over some of the current pressures faced by healthcare and their applications have therefore grown considerably. Radio Frequency Identification (RFID), a wireless automatic identification technology [18], [19], is rising as the “next disruptive innovation in healthcare” [20], and is believed to be able to bring about an “industrial revolution” just like the Internet and the barcode did some decades ago [21].

The healthcare industry is becoming an important market niche for RFID implementations as it generates several potential benefits including the improvement of patient safety [22]–[28]. A wide range of RFID applications has been used in different hospitals around the world to ensure patient identification [29]–[31], medication management and safety [32], [33], specimens identification and tracking [34], blood derivatives tracking and blood supply chain management [35], newborns identification and tracking [36], staff identification and location [37], and response to mass casualty and pandemics [38], [39]. In particular, a lot of interest is given to the area of material and asset management, which is becoming the mainstream application of RFID in healthcare facilities [6], [40], [41]. The interest in RFID has not only been from academics [42]. Practitioner communities have also realized the great potential of RFID and are advocating its usage. In Mexico, the federal health-insurance program mandated manufacturers and distributors to embed RFID tags on drugs sold to the millions families covered under this insurance program [43]. Also, in the US, the Food and Drugs Administration (FDA) has advocated the use of RFID in an attempt to “improve the safety and security of the nation's drug supply” [33], [44].

Despite the importance given to RFID in this sector, there is a lack in knowledge with respect to the necessary implementation model to support its adoption and evaluate its value. We therefore aim to bridge this gap by assessing the prevailing issues, benefits, implications and limitations of implementing RFID in hospital settings to manage strategic mobile medical equipment. Consequently, the research approach privileged is a detailed *longitudinal exploratory case study*. This paper is organized as follows. In the next section, we present a brief overview of RFID and its implementation in healthcare while the third section analyses the conceptual context of this research. Section 4 provides essential information on the methodological approach. Results are presented and discussed in section 5 whereas section 6 presents some concluding observations.

5.2 Technical context: RFID technology

RFID is considered "the latest and most advanced" Automatic Identification technology (AIDC) [19] due to its particular capabilities to identify, locate, track and trace in real-time objects across the extended supply chain. Various technologies fall under the AIDC family, including optical recognition, biometrics, card technology, contact memory technology, bar coding and RFID technology.

Bar coding is the most commonly used technology for product identification. However, RFID is perceived as a more efficient and effective technology with many proclaiming it as the next generation barcode [45], [46]. In contrast to bar coding that allows only identification of "class of goods", RFID permit unique "item-level" identification ensuring availability of real-time information on single physical objects or persons. However, the most distinctive difference between these technologies is that RFID is a non-line-of-sight technology [19]; hence, RFID tags do not need to be "seen" by the readers or "be" in direct presence of the reader to be detected; they only need to be within reader's reading range. This offers particular opportunities for operational improvement in environments where several items circulate at the same time [47], as RFID open the door to simultaneous reading of numerous tags, with some authors reporting that as many as 1000 RFID-enabled items could be read in a bit over 1 minute and a half [48]. Moreover, with RFID information programmed in the tag can be overwritten as the RFID-enabled object move along its life cycle activities. Besides, RFID has the capability to cope with harsh environments, where barcodes would not endure due to their lack of durability, thus overcoming some barcoding readability issues [45], [49], [50].

The term RFID refers to a set of technologies that uses radio frequency to transmit information [19]. An RFID system consists of multiple components including RFID tags, RFID readers, and the RFID middleware. RFID tags have a chip and antenna, which allows data transmission to readers via electromagnetic radio waves. RFID tags can be classified as passive, semi-passive, and active, which are suitable for different applications. Passive tags do not have a power source; thus, rely on RFID reader's electromagnetic field to trigger signal transmission. On the other hand, active tags have an internal power source used for signal broadcast. In recent years, hybrids RFID systems are emerging, which combine RFID with other technologies such as IR, sensors, GPS, GSM, and GPRS telecommunications [51], [52]. In a healthcare environment, various RFID technologies may share a place and play complementary roles. For instance, active RFID will be more likely used when looking at tracking mobile medical equipment [6], whereas passive tags will be often seen attached to medications and laboratories specimens [34]. Some hospitals had as well opted for hybrid solutions for various applications including patient tracking [52].

RFID readers are responsible for information retrieval and acquisition, allowing information flow between the tags and the host system by means of the RFID middleware. Readers' antennas emit and receive radio signals activating tags and capturing the data stored in them. Readers are composed of various subsystems, including the reader API, which permits the capture of RFID tag events; the communications component that handles networking functions; as well as the event management module that oversees the data captured [53].

The RFID middleware is key element of the RFID system, which is responsible for filtering and processing the raw data gathered through readers, and then routing useable data to the appropriate existing enterprise application systems [54], such as hospital information system (HIS), and patient management systems in healthcare settings. RFID make possible to seamlessly integrate data captured through RFID hardware components with backend databases and applications, as well as decision support system, here is where the real value of implementing RFID lies [11]. It is important to take into consideration that a high volume of data would be collected through an RFID system, which could pose many challenges on existing data management systems. Hence, in order to achieve the utmost value from RFID it is critical to ensure the transformation of raw data obtained via RFID tags into useful information [55].

5.3 Conceptual context

5.3.1 RFID adoption in the healthcare sector

Healthcare facilities turn to RFID in order to better manage assets, improve inventory management, prevent newborn abductions, ensure optimal patient medication management to avoid errors, keep mentally impaired patients from walking away unnoticed, track and match blood for transfusions, track pharmaceutical supply chains to combat counterfeiting, improve business processes and workflows, and the list goes on [6], [22], [28], [56]. Studies interrelated to RFID applications and impacts in healthcare related activities are mainly case studies, conceptual papers and simulations.

Several case studies have been reported in the literature. For instance, Wang and co-authors [38], presented results from the RFID feasibility project at a Taiwanese hospital to combat SARS. The project demonstrated the feasibility of RFID in hospitals, but also highlighted the presence of technical difficulties, as well as difficulty on persuading medical professionals to accept and use the system. Kannry et al. [57] describe a study at a US hospital designed to measure the effectiveness of using RFID for bed management. Janz et al. [58] report on results from a “proof of application” and outline that RFID can support the measurement and control of workflow processes in hospitals and provide timely business intelligence for the healthcare optimistically impacting the quality of care delivered. Furthermore, some simulations have also been carried out to measure the value of RFID in this sector [59], [60].

In addition to the above mentioned empirically based articles, some conceptual papers have been published and include among others the work of Ngai et al. [27] that proposes the architecture for an RFID-based healthcare management system that is intended to reinforce patient and medication safety, improve inventory management of pharmaceuticals, as well as improve patient identification and in-hospital tracking processes. Kumar et al. [22] suggest a three-stage implementation approach for RFID adoption in healthcare environments. Tzeng et al. [61] offer a framework for evaluating the business value of RFID technology within healthcare activities drawing on the experience of five early adopters from the Taiwan healthcare industry. Aguado et al. [62] present a review paper illustrating how the application of RFID in healthcare can enable this industry to overcome existing technological and workflow limitations. Chen et al. [63] study key factors that contribute to the intention to continue using RFID. Results show that perceived usefulness of front-end interoperability and performance expectancy have significant relationships with confirmation experience; confirmation experience has a significant relationship with satisfaction, which in turn relates to intention to continue using RFID.

Though many papers point to numerous potential benefits of RFID applications in healthcare (Table I), there is still an important knowledge gap regarding the prevailing issues raised by the implementation of RFID applications in healthcare organizations and the actual measurable and realized benefits generated by such implementation. As stated by Ngai and co-authors, "the design and implementation of an RFID system is not a simple and straightforward process" [64, p.2585]; yet a number of RFID implementation frameworks have been proposed in the literature [49], [64], [65] and many RFID-based projects have been developed in a broad range of industries. For instance, Ngai et al. [64] propose an RFID implementation framework that was evaluated through a case study in the textile industry, which spans over seven stages, from project feasibility and scoping (stage 1), project team formation (stage 2), 'AS-IS' assessment (stage 3), process redesign (stage 4), hardware adaption to the environment (stage 5), system implementation (stage 6), to continuous improvement (stage 7). This paper intend to bridge this gap, hence an implementation model for RFID undertakings in healthcare settings is presented in details in subsequent sections.

5.3.2 Finding value for RFID adoptions in healthcare

IT is perceived as enabler for the improvement of care delivery, the enhancement of operational efficiency, the reduction of organizational expenses, and the achievement of competitive advantage [7]. However, creating business value from investments in such technologies has been for long a great concern to organizations and represents a prominent inhibitor factor for their adoption [66], particularly when adopting emergent technologies such as the case of RFID. It is reported in the literature that RFID could potentially offer great benefits for healthcare organizations, even outside the boundaries of a hospital to benefit the extended healthcare supply chain as well [6], [61], [67].

As demonstrated in Table I, the prospective benefits of RFID technology comprise a wide range of tangible benefits, including reduction of operation costs, reduction of manual operations, improvement of healthcare efficiency; as well as a great deal of unquantifiable benefits, making a holistic assessment of its economical profitability a very difficult task [24], [47], [48]. Accordingly, the business case behind RFID implementation is very hard to demonstrate. Many have the perception that RFID is too expensive to deploy [41], [57] since the actual cost of RFID integration is not only limited to hardware (e.g. tags and readers) and software components of the RFID system, in fact, the true investment goes well beyond that. Smith and Konsynski [68] identified a range of costs related to RFID implementation, including cost of tag and readers, cost of embedding the tag into products, cost of installing readers, cost associated to systems integration, cost of training the personnel and re-organization, as well as the cost of implementing application solutions. HCOs work with limited budgets and face great scrutiny regarding the way they use and allocate their resources. Consequently, stakeholders within the healthcare arena question whether an investment in RFID could be justified since a multitude of the benefits offered by this technology are intangible, and therefore cannot be simply measured through traditional methods (e.g. return on investment: ROI) [69], [70]. Given the intrinsic complexity to quantitatively assess the return on investment of RFID adoption projects, a significant number of organizations prefer not to get involve in early stages of the RFID adoption cycle, instead they would rather learn from the experience of early adopters, and possibly become involved during the later stages of innovation diffusion as “late majority” and “laggards” [71]. In order to ascertain the real benefits of IT implementation, Clemons [72] advocates the need to evaluate, during pre-investment stages, tangible and intangible benefits of the targeted IT implementation in order to transform these un-quantifiable benefits into financial metrics [69],[72].

Table 5-1 Potential RFID benefits in healthcare

Benefit type	Benefits	References
Direct / Tangible	-Increased patient safety	[4], [22], [24], [29], [35] [55], [56], [60], [62], [67] [70], [75]
	-Improved patient identification and location in case of health crisis	[28], [38], [39]
	-Increased patient satisfaction	[22], [23], [55], [56], [70] [75]
	-Enhanced clinical services quality	[4], [22], [23], [55]
	-Cost savings	[6], [22], [23], [55]
	-Improved asset visibility, and utilization	[6], [23], [28], [55]
	-Improved inventory management	[4], [22], [28]
	-Improve drug management and administration	[6], [23]
	-Improved healthcare supply chain	[55]
Indirect / Intangible	-Improved business process and workflows	[4], [6], [22], [56], [58] [60], [61], [70], [75]
	-Improved information flow and visibility	[6]
	-Reduced clinical staff frustration	[6], [67], [74]
	-Gained competitive advantage	[70], [75]

Even though the business value of RFID adoption in healthcare still somewhat uncertain, some studies have investigated the expected benefits or anticipated advantages that RFID can offer to healthcare organizations. Let us mention the work of Evans and Piechowski [73] that identified that most of US healthcare industry believed that RFID technology could improve patient safety, business process and productivity. Castro et al. [6] discuss how RFID holds the potential to improve visibility and management of critical mobile assets, to eliminate non-value added activities and to generate intelligent processes. Wang et al [38] highlight three potential benefits of RFID adoption in Taiwan hospitals, including reduction of cost and time, improvement of patient safety and medical services. Zhou and Piramuthu [24] point some unquantifiable benefits of RFID such as safety and security, as well as better tolerance for longer payback periods. Castro et al. [6], [74] discussed how a better level of visibility of assets contribute to intangible benefits such as the reduction of clinical staff frustration, and the improvement of organizational climate and work conditions. Other authors have discussed the potential of RFID to enhance customer satisfaction, gain competitive advantage, improve patient safety, improve patient satisfaction, as well as refine business process [70], [75]. Indeed, Tzeng et al. [61] accentuates in the potential to derive business value from RFID applications through refining business processes and expanding the business model in healthcare organizations. Through an evaluation of a RFID implementation process model in healthcare, Bahri [67] outline that RFID will make possible for the hospital to enhance patient care, ensure the security of its doctors, nurses, administrative staff and patients, and make better the working environment for nurses and administrative staff. Roh et al [48] discusses that various intangible advantages could come from innovative use of a technology, such as RFID, including the creation of new business processes.

5.3.3 IT performance evaluation in healthcare

The focal point of healthcare organizations is patients' safety and well-being, which represents a key determinant of the quality of healthcare services; conversely, many patients are receiving poor or inadequate quality care [11], [76]. Multiple issues, including inefficient inventory management and control, deficient products and assets tracking, lack of visibility of information, as well as disrupted workflows and processes are greatly affecting the overall performance of healthcare operations. Healthcare systems are very complex in nature. The prevailing norms, practices, and culture characterizing this sector have an impact on efforts to increase system performance [10]. Moreover, the distinct differentiation of professional groups into subcultures based on occupation and skills is vivid proof of it. Each group has its own mind set in terms of priorities, outcomes and quality of care; consequently, they may give dissimilar importance to different aspects of quality [10], [11], which could in turn represent a barrier to the promotion of safety and performance improvements in healthcare [10].

Performance measurement offers a unique opportunity for decision makers, since it gives them an opportunity to ensure health system improvement and accountability [77]. Although integrating an effective performance measurement system into an organization is essential in order to align its operations with its strategic objectives; many organizations are not successful at addressing this issue [78]. In the healthcare context, the performance of support services, such as material and asset management, is perceived to have an impact on the overall performance of the health system, and consequently the performance of care delivery [79]. HCOs could possibly be able to enhance their patient care performance by working on "efficiency and cost reduction" targets [80]. Asset managers concur that real-time operational, economic and asset life key performance indicators (KPIs) are vital for topnotch asset management [81].

Previous work on the assessment of the impact of RFID has been mainly carried out in the supply chain management context in other sectors [82]. From a supply chain perspective, many authors have explored the subject of performance measurement, including the work of [83] and [84]. However, given the discussed particularities of this sector, many of the indicators identified and measure in other industries are not applicable within the context of healthcare.

Moreover, when investigating the area of asset management, there is paucity in terms of a framework for asset management performance measures; consequently, there is not a guide or reference model for medical equipment asset management performance measures and evaluation, particularly when evaluating the impact of integrating RFID technology to such processes. Purbey et al. [78] shed light on evaluation of performance measurement systems for healthcare processes presenting a framework for the selection of a suitable performance measurement system, which proposed to measure performance from a multi and interrelated perspective that is efficiency, effectiveness and flexibility. A study by Chowdhury et al. [11] highlights the importance of considering measures such as efficiency, acceptability, equity and quality to evaluate the performance of health service delivery. According to the authors, efficiency plays a very significant role in performance improvement since it reflects whether an organization is making the best use of its available resources, such as best use of available medical equipment in hospital facilities.

When evaluating performance related to asset management activities at HCOs, productivity of materials resources needed to deliver care is pertinent. According to Smith et al. [77] productivity of operations within healthcare involves the degree to which the resources used by the health system are used in an efficient manner. Indeed, measures such as "*equipment utilization rate*", "*equipment order turnaround*", "*equipment shrinkage*" are of relevant importance for material managers and hospital's stakeholders since it reflects whether or not valuable assets such as medical equipment are fully utilized for the benefit of patient care delivery and for the financial health of the hospital.

5.4 Methodology

RFID implementation in healthcare cannot yet be grounded in theory and remains under investigated [27], [56], [57], [61]. As the overall research objective here is to gain a better understanding of RFID implementation in healthcare organizations, the research design clearly falls in the realms of exploratory research. The research was conducted over two years at one hospital (hereinafter referred to as "hospital A").

With some 180 medical specialists and approximately 30 medical units, *hospital A* is nearly 100% Wi-Fi and has adopted medical information systems. In order to manage assets inventory, maintenance and repair, the hospital relies on various enterprise applications, and uses a barcoding. Hospital management demonstrated interest in the implementation of an RFID-based mobile asset tracking system to improve the management of critical medical devices.

In order to allow triangulation and strengthen the validity of the results [85], multiple sources of evidence were analyzed:

1) Analysis of internal documents such as clinical and non-clinical procedures and directives;
2) Multiple on-site observations;

3) Panel studies (same focus groups over a period) and semi-structured on-site interviews over multiple points in time (two year period);
4) Continuous analysis of data generated by RFID tags and the corresponding information from the asset tracking system.

The research design therefore combined both unobtrusive and obtrusive data collection methods that generated large amounts of qualitative and quantitative data. For instance, the quantitative data provided by the RFID-based mobile asset tracking system (1317 tags readings) corresponds to a rather efficient and unobtrusive data collection method to assess the value of the RFID-based mobile asset tracking system. On the other hand, the obtrusive data collection methods such as the semi-structured interviews and the focus groups allowed the researchers to gain additional insights into the existing legacy systems, the needs and requirements for the future RFID system, and the priorities and divergent issues prevailing at each stage of the RFID implementation process from the perspective of the different groups of participants and stakeholders.

Special attention was also paid to acquire an in-depth understanding of workflows within the hospital. A process-based approach was retained for several reasons. First, it provides “a more dynamic description of how an organization acts” [86, p. 2]. Second, it is known to be particularly pertinent for RFID project [50]. As noted by Murphy [87], “only when an organization fully understands its business processes, then RFID could be truly effective”. Third, the process-based approach proved to be a valuable graphical tool for anchoring discussions, especially in focus groups, for reaching a consensus among research participants; for instance, when deciding on the technological scenario to be selected, or for validation purposes; for instance, when validating existing business processes. These processes were modeled using a drill-down approach with Aris Toolset software from IDS Scheer.

The thirty-one (31) participants represent key managers, professionals, medical and non-medical staff as well as technical specialists from nine (9) organizations (Table 5-2). Members of the research team from one research center and from two universities are considered as participants because they played different roles ranging from full participants (when building the technological scenarios) to participants as observers (when mapping actual business processes).

Table 5-2 Profile of Participants

Entities	**Type of participants**		**Number of participants**
Hospital A	Top-management	- Hospital director	1
	Medical technical department	- Manager - Biomedical engineers	3
	Medical units	- Manager for ward A & B T - Team manager (A & B) - Team manager for other medical wards - Head nurses	8
	ICT departments	- Manager - automation - Manager- ICT - Technical expert	3
	Central storage room	- Supervisor - Clerk	2
Total			**17**
Hospital association	Chairman		1
Four TPs	Top managers, technical experts and professionals from TPs (technological partners)		8
UBRC	Director of UBRC (University-based research center)		1
Two universities	Professors and PhD candidates		4
Total			***14***

5.5 Results and discussion

Results from the case study are presented in a linear manner following five consecutive phases, namely pre-feasibility, feasibility, RFID scenario building and validation, implementation in a real-life setting, and benefits assessment, although iterations between these phases have occurred. These five phases are in line with the implementation model recently proposed by [64].

The main results obtained from each phase are summarized in Table 5-3.

5.5.1 Pre-feasibility

The main objectives that could be derived from an RFID-enabled mobile asset management system were discussed in the first focus group. Consensus on the hospital needs concerning critical assets was rapidly reached on the following objectives:

1) Need to *improve real-time monitoring and management* of mobile assets, including assets availability rate, utilization rate, status information, and real-time localization;
2) Need to *reduce delays in patient care* by responding more efficiently and faster to emergencies and unpredicted critical events, and therefore improve patient care;
3) Need to *improve productivity and efficiency* by reducing the time hospital staff, including physicians, nurses, technicians, etc., spends in locating misplaced assets;
4) Need to *improve communication and decisions activities* by keeping up-to-date equipment status on maintenance, sterilization, decontamination, etc.;
5) Need to *reduce overbuying, unnecessary rentals, and under-utilization* of hospital assets;
6) Need to *eliminate costly replacement* of lost or stolen medical equipment.

Mainly, the overriding concern expressed by participants deals with the improvement of the quality of healthcare services, either directly as noted from objective 2 or indirectly as implied by objectives 1, 3 and 4. Cost effectiveness objectives, namely objectives 5 and 6 are placed in second rank.

The development of strategic alliances among technological and non-technological partners proved to be based on their respective competences, resources and strengths. However, the technology partners' readiness was the factor that contributed the most to the hospital's decision to go ahead with the RFID project.

As all participants wished to minimize financial and time investments in the RFID-based project, they agreed to limit the scope of the project to *one type of mobile assets* and *three hospital units*. Participants from the hospital felt that *infusion pumps* would be particularly pertinent and rather strategic for the *hospital A*. Infusion pumps are expensive equipment that are used all across the hospital, cost over € 1,500 each, and are considered as “high-risk” medical equipment given the high level of threat any failure could represent to patient’s health. The main problems with the infusion pumps at hospital A relate to the fact that they are continually misplaced, hoarded, or hidden around the hospital; rendering them very difficult to find and restock. According to hospital participants, lack of visibility on their location and status results in continual shortage of infusion pumps, which in turn entails several significant drawbacks, including consuming staff time on unnecessary equipment search, delaying care delivery, and postponing maintenance and repair activities. Furthermore, some thirty (30) infusion pumps have disappeared over from the last few years, representing a 25 percent shrinkage rate and resulting in additional pumps purchase.

The decision was also easily reached to limit the RFID project to two medical wards (Ward A and Ward B) where the availability of infusion pumps is considered critical. According to information validated with wards team managers, approximately 90% of patients treated in Ward A, a 35-beds surgical recovery unit, require an infusion pump for delivering fluids, medication or nutrients while Ward B, an orthopaedics unit with 40 beds, is a slightly larger unit where infusion pumps are necessary for the treatment of 60% of its weekly patients. As infusion pumps are stored in a central storage unit, the participants felt strongly that this latter unit should also be included in the pilot project as well. The central storage unit of *hospital A* furnishes medical units and departments with all necessary general and medical supplies.

With regards to the medical equipment, the central storage room is responsible for warehousing activities, including receiving, put away, and picking of equipment, for distributing the equipment to wards, and for restocking it from wards.

Table 5-3 Main Results of RFID Implementation

Implementation phase	Main decisions	Prevailing issues
Pre-feasibility	- Defining main objectives - Selecting technological and non-technological partners - Circumscribing the scope of the RFID pilot project - Appoint a project champion	- Improvement of the quality of healthcare services as the overriding concern. - Readiness of technological partners Low initial time and money investments. - Limit pilot to one mobile asset and three hospital units - Limit pilot to an optimal physical layout to cut down the costs of RFID infrastructure
Feasibility	- Selecting critical asset management activities related to infusion pumps for the RFID pilot project - Validating the existing business processes for the selected asset management activities and identifying areas of improvement - Assessing the functional and technical requirements of the RFID pilot project, including the level of granularity and precision	- Cleavage between administrative concerns versus clinical concerns - Limit opportunity evaluation to two critical activities: warehousing and usage - Evidence of some operational inefficiencies - Cleavage between and within the different perspectives - Limit the functional requirements to tracing and tracking, with an added functionality on status (in-use versus no- in- use) - Limit costs of RFID infrastructure by maintaining *visibility at a ward level* - Ensure scalability of chosen RFID solution
RFID scenario building and validation	- Assessing the gap between the existing situation (AS IS) and the RFID-enabled situation (TO BE) - Validating the elements of the proposed infrastructure for the RFID-based Wi-Fi asset management solution - Validating the technological scenario	- Easily reached consensus
Implementation in a real-life setting	- Defining modalities and agreement for RFID system deployment - Agreeing upon pilot duration among partners - Ensuring training of key personnel to achieve system appropriation	- Technological partners agreed to lend to *hospital A* all components of the RFID-enabled asset-tracking platform (e.g. tags, software), and carry on all necessary system integration at no cost. - Consensus reached on initial pilot duration; thus, as project advanced new datelines were set to ensure vast data collection. - Easily reached consensus among participants
Benefits assessment	- Determining specific benefits of RFID for asset management - Analyzing of KPIs - Determining limitations of current available technology	- Define a KPIs framework for asset management - Envision a technological solution where the RFID tags would be an integrated element of the medical equipment

The flow of mobile medical equipment (including the infusion pumps) within the three units retained for the pilot study is displayed in Fig. 1. Taking into consideration the physical layout of the chosen pilot zone, the general disposition of the two medical units is well fitted for minimizing the complexity and the costs of an eventual RFID infrastructure, a primary concern for the technological partners that was not equally shared by the other participants. Indeed, wards A and B are co-located on the same floor, sharing a common entrance hallway and access to elevators, which are the only two points of entrance to these two units. When storage room's clerks distribute infusion pumps to Wards A or B, they will access these wards by either of these two entrance points. Moreover, when either of these units needs an infusion pumps and that there is a stock-out at central storage room; their first choice for procuring their required equipment is the other ward; hence, nurses from ward A will try to find an available pump in ward B and vice versa before looking at other units. The storage room is located in a different floor at a different hospital wing.

Various authors agree that the presence of project champions represents a chief factor in facilitating new technology adoption process [5], [49]. It was highly important to define at an early stage of the project a project champion among the hospital management participating staff. The latter, it is consider a valuable strategy to successfully deal with issues that may rise due to necessary process redesign and resistance to change. The manager of medical technical department was the link between researchers and technological partners with the strategic and operational staff at the hospital.

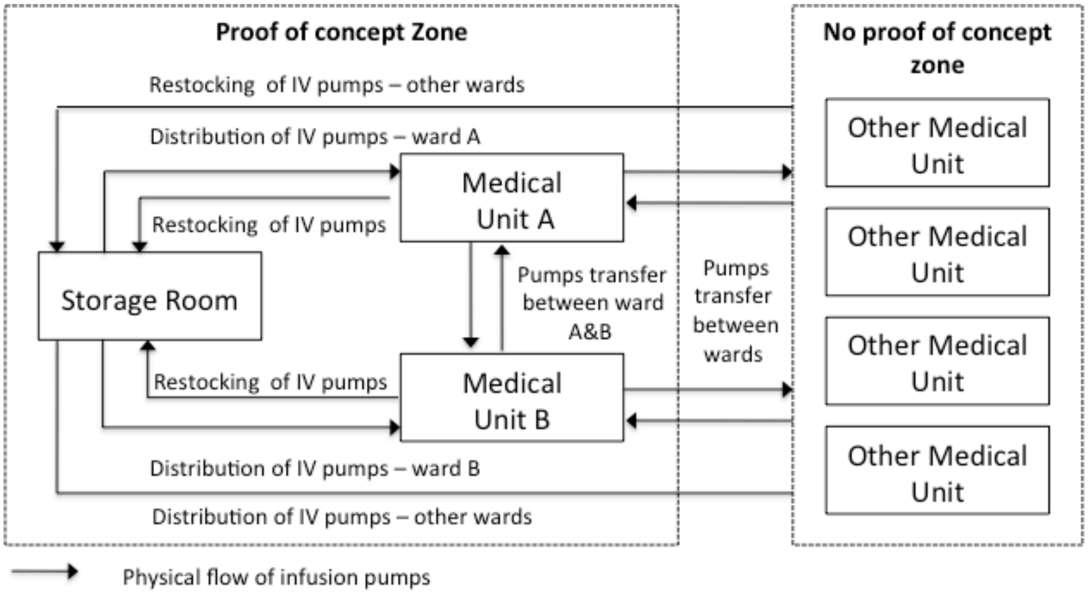

Figure 5-1Flow of infusion pumps at hospital A

5.5.2 Feasibility

From the internal documents and the on-site observations and interviews, asset management related to infusion pumps covers five broad activities: procurement, warehousing, usage (point of care), maintenance and repair, and, final disposal or recycling. However, participants retained only warehousing and usage activities to be targeted by the RFID pilot project (indicated in grey in Fig. 2). Activities such "maintenance and repair", and "disposal and recycling" although implied by the previously agreed objective (Objective 4: Need to improve communication and decisions activities by keeping up-to-date equipment status on maintenance, sterilization, decontamination, etc.) were discarded. Strong arguments were made by team leaders to focus on the clinical dimension of the pilot project; one team leader stated "the most critical questions we should be asking are: how many pumps do we have and how are we going to use them?" The more managerial and operational issues such as maintenance were second ranked for the pilot project; though poorly maintained, contaminated or even broken infusion pumps are of no use. Cleavage between administrative perspective and the clinical perspective became apparent.

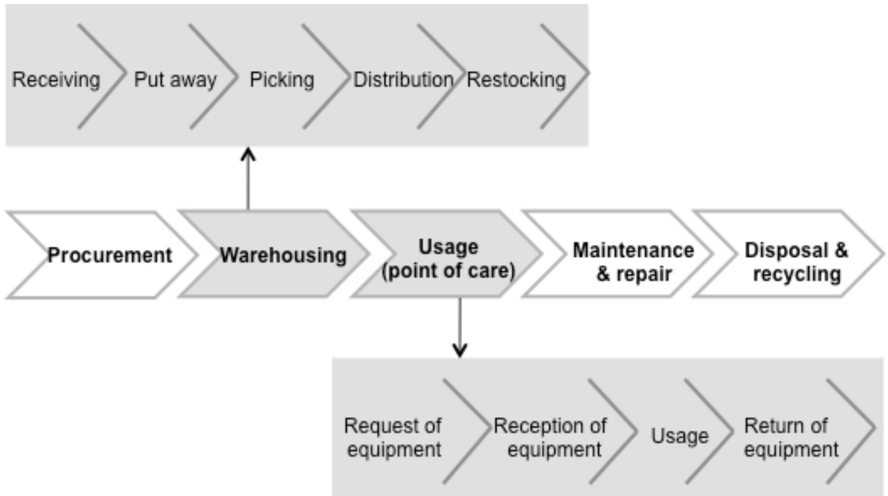

Figure 5-2 Asset management activities related to infusion pumps

Once the focus on warehousing and usage activities was agreed upon, prevailing importance was given by participants to two aspects: *first*, the assessment of existing operational inefficiencies and, *secondly*, the requirements of the RFID application to overcome such inefficiencies.

"AS IS" business processes were mapped by researchers and validated with key personnel to ensure reliability of the data collected from on-site observations and the semi-structured interviews. Existing processes were analyzed in order to find areas of opportunity for improvement, such as eliminating unnecessary manual activities or duplications. Several operational inefficiencies affecting mobile asset management were then identified. Inefficiencies such as recurrent inventory shortages at central storage room, service delays since infusion pumps are unavailable on demand, asset sub-utilization, wasted staff time since biomedical engineers, storage room clerks and nurses spend time searching for equipment, were caused by the lack of visibility of equipment location and the presence of information "silos" among hospital services.

The above inefficiencies also arise from some discrepancies between the "formally established processes" (or the way it is supposed to be done) and the "actual processes" (or the way it is actually done). Several comments are symptomatic of the cleavage between the clinical and non-clinical perspectives: for instance, according to personnel from the central storage room and the medical technical department, "nurses are not using the infusion pumps properly; they drop it, etc., so they get out of order often and therefore are not available. In case of breakdowns, nurses are supposed to call us; instead, nurses usually put the equipment in the corridor with a paper that says "defected" and it can stay in the corridor for up to four days and nobody does anything, until finally someone calls. Everybody thinks that they are so busy that no one makes time for that."

Cleavage also exists within the *non-clinical perspective*, for instance, staff from the central room storage reported that "the biggest problem is the delay of the technical medical department to do the maintenance. In some occasions, they have 20 to 25 pumps left in the technical department and no one is fixing them." As for the *clinical perspective*, the different professional groups do not put a uniform front either. For example, the team leader from Ward A made the following comment "the shortage of infusion pumps could be a consequence of an inappropriate usage of the equipment, since sometimes nurses use pumps for patients that could be treated manually". This is echoed in another similar comment from one physician, "Nurses use the pump for everything. There is a number of pumps used by patients that not necessary need one, nurses use them for everything because it is easy for them." Consequently, various team managers agreed that from a clinical perspective some protocols should be established in regards to the usage of critical equipment with team leaders from wards A and B commenting "they should establish some rules of who can use it (pump) and for what kind of treatment", this view is shared by other colleagues with one other team leader stating that there is a need to "determine that we will use the pumps only in specific situations".

The following proposition was made by the four technological partners: The deployment of an RFID solution that allows the identification, location, and tracking would resolve to a certain level some of the above mentioned inefficiencies and would directly resolve issues concerning lack of equipment location visibility. Consensus was easily reached to retain such a proposition, which basically represented the overall statement of the functional requirements of the RFID pilot project. Indeed, available information regarding equipment location will permit staff to look for equipment at a known location, thus reducing time devoted to search, and will allow it restocking at the storage room, thus increasing service responsiveness. The only issue is that having information on equipment location does not guaranty its availability. If an asset is located but it is in use, staff will have to continue looking for an available one. As a result, knowing the status of the infusion pump, in use or not in use, will have a direct impact on most of the inefficiencies noted previously and was retained as an additional functional requirement of the RFID pilot project.

The technological feasibility of the RFID future implementation was carried out by technological partners and university-based researchers, who worked closely with IT and technical staff at *hospital A*. Moreover, opportunities and constraints in the selected zones (wards A and B, central storage room) were examined. Knowledge of the environment where the implementation will take place permits to evaluate different factors; including possible installation issues and potential interference of objects, as well as to eliminate certain technological choices that would not be suitable in such environments. An RF finger printing of specific areas of the hospital was undertaken using a spectrum analyzer in order to measure possible interference and Wi-Fi coverage at specific areas at *hospital A*. From the site surveys, it was noticed that Wi-Fi coverage was weak inside rooms at wards A and B; hence, room-level visibility of IV pumps would implied installation of additional Wi-Fi access points, with the necessary wiring, etc. Participants agreed that for the scope of the pilot project *visibility at a ward level* will be sufficient; thus, only information of whether or not a specific infusion pump is inside ward A or B at a given time will be available.

Finally, particular consideration was given to the selection of a "scalable solution" that would permit to use the foreseen RFID infrastructure in order to improve management of other mobile asset, as well as for additional applications according to the eventual needs of the *hospital A*, for instance, possible applications of RFID to help with the identification and location of mentally challenged patients and staff was regarded as an area of interest.

5.5.3 RFID scenario building and validation

Scenarios integrating RFID technologies were modeled using a drill-down approach with Aris Toolset and validated in an iterative manner with participants. Once scenarios were built, a gap analysis between the “AS IS” situation and the “TO BE” situation was performed for all activities pertaining to warehousing and usage (see Figure 2). Fig. 3 displays an example of the gap analysis for two integrated activities, namely “picking” and “distribution”, which falls under the broad set of warehousing activities.

The analysis of the existing processes performed during the previous phase (feasibility) permitted to identify actual "pain points" and evaluate opportunity zones within all analyzed processes. For instance, when analyzing activities involved in the "As-is picking" and "As-is distribution" processes, participants determined that among the existing activities, four (4) activities were not adding value and therefore were suitable candidates for improvement (Fig. 3). Today, when there is a request for an IV pump, the warehouse clerk needs to go to the location of their designated shelf to validate whether or not they have an available pump (activity 1), implying unnecessary staff movement. Also, in order to keep their inventory system updated, clerks need to scan bar codes attached to pumps, scan sheet containing destination wards bar codes, and then link the equipment to the user ward (activities 4,5,6), demanding additional manipulation of equipment and adding labour time to the distribution process.

Various technological scenarios were built for each process in order to make the most of the potential opportunities of RFID to lessen identified "pain points", which are at the source of inefficiencies of core existing business processes. Figure 5.3 depicts one of the RFID-enabled scenarios (TO BE) built for activities involved in the "picking" and "distribution" processes. As illustrated on the "To Be" process, the areas of opportunity assessed when evaluating the existing situation could be effectively improved with RFID integration. For instance, warehouse clerks would not need any longer to go to the dedicated shelf to validate if there is a pump available; instead, he will have access to real-time information about pumps availability through the asset tracking system. Various activities could be eliminated since real-time information on warehouse inventory will be seamlessly collected through the RFID-enabled asset tracking system. Activities such as "register exit of pump in WMS" and "update inventory levels in WMS", activity 7 and 8 respectively, could be now performed automatically as tagged assets leave storage room.

This portrays only some of the opportunities evaluated during the RFID scenario building and validation stage, since various scenarios were built not only for the "To-be picking" and "To-be distribution" processes, but also for the rest of the "warehousing" and "usage" activities.

Gap analysis of "As-is" vs. "To-be" processes permitted to evaluate the capabilities of RFID to increase productivity and quality of operations, validate some of the numerous expected benefits, as well as assess possible technological limitations of RFID-enabled scenarios. Once the “To Be” scenario to be deployed was agreed upon, technology partners worked closely with hospital’s ICT team in order to determine system architecture requirements necessary to support the new processes integrating RFID. For instance, verify whether exiting Wi-Fi infrastructure could support scenario implementation or if changes were needed. Since there was no Wi-Fi connectivity available in the storage room, the IT team at the hospital agreed to ensure Wi-Fi coverage at that particular location. All requirements were discussed and agreed upon. Consensus was easily reached for all decision points pertaining to this third phase.

5.5.4 Implementation in a real-life setting

During this phase, the “To-be” processes of the retained scenario were reproduced and integrated into real processes at hospital A. Initially, partners agreed on a six-week pilot testing for the deployed application. This very short period seemed preferable since the technological partners were lending at no cost the elements required by the RFID infrastructure.

However, as the project evolved, the proof of concept ended up running over seven (7) months. The longer duration of the pilot project permitted to collect more vast unobtrusive data than originally planned.

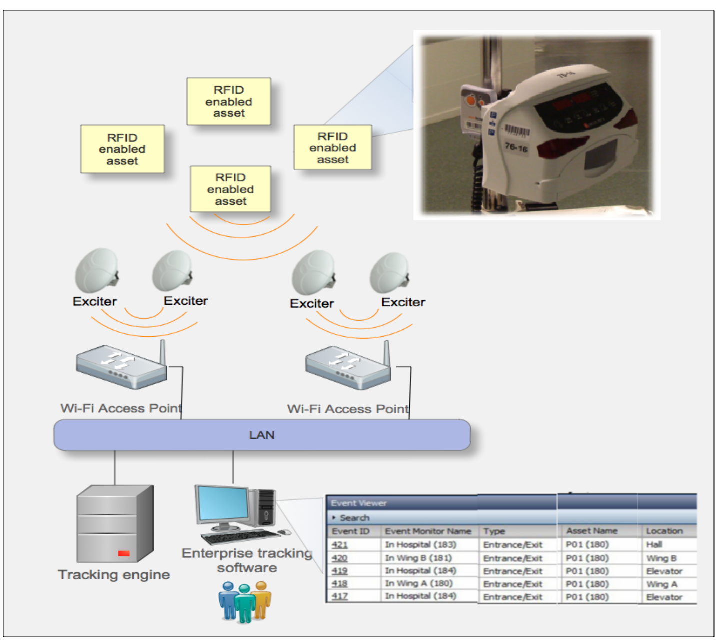

Figure 5-3 RFID-enabled asset tracking system

Figure 5-3 depicts the RFID-based asset tracking system as implemented at hospital A. As illustrated on this figure, the RFID-based asset tracking system as implemented at hospital A included various Wi-Fi access points and exciters, numerous Wi-Fi-based RFID active tags, one tracking engine, and one enterprise tracking software.

Actual deployment of retained scenario included among others the following activities:

- *Site survey*: prior to the deployment of the RFID-enabled platform, a general site survey was carried out by technical experts, researchers, and appointed staff to verify installation of previous requested elements such as power sockets, additional access point at storage room, etc.;
- *Physical mounting of system elements*: mounting of exciters at all determined locations at ward A, ward B and storage room was performed, ensuring that both exciters and power adapters for the exciters were securely mounted;
- *Software configuration and integration*: carried out by technical partner staff with support from hospital's ICT department;
- *Tag-positioning test*: perform in order to identify best RFID tag position to ensure that tags would be readable and would not interfere with equipment handling and usage;
- *Tag programming and activation*;
- *Test runs*: performed by technical experts from the technological partner team to ensure tags readings and exciters functionality.

A sample of tagged pumps was used to test the system and carry out all necessary system tuning. Once the system was tested and tuned, the rest of the tags were ready to be mounted on infusion pumps. Forty infusion pumps were tagged and were assigned an identifier between 1 and 40; hence, each tagged pump has a corresponding asset name between P01 and P40 in the asset tracking system.

A system demonstration was given to key participants, including among others the manager for wards A & B, and the technical department manager. Participants were able to see the movement of the tags within the proof of concept zone, for instance:

- Through the exciter placed at wards A and B hallway entrance, it was possible to have information of equipment as it enters and leaves these wards;
- The exciter in front of elevator doors allows to record information of the infusion pumps as they enter and leave these wards through the elevators;
- The exciters at the entrance of wards A and B detect and record any RFID-enabled pump as it enters or exits wards A or B, providing visibility on asset used by either ward and offering information to record equipment transfers between wards A and B as well.

In order to facilitate system appropriation by users, system training was given by technology partners to key personnel at the hospital premises. These trained personnel will in turn be in charge of operational staff training, including nurses. Staff training was undoubtedly necessary to support RFID implementation and to motivate the personnel to use and benefit from the opportunities brought by the technology. For instance, nurses were trained particularly on usage of tags push bottoms, so that information regarding pumps status (in use vs. not in use) could be collected. Technical medical manager was trained on asset-tracking functionalities, data collection techniques and reports generation, among others.

5.5.5 Benefits assessment

During a seven-month period, participants monitored the RFID deployment, and collected and analyzed the unobtrusive data generated by the asset management system in order to substantiate the anticipated benefits of such implementation.

Hospital personnel could have real-time access to information about the location of any RFID-enabled pumps as they move through the pilot zone over time. Further, information collected through this system, over the pilot period, permitted to have visibility not only of the location of tagged pumps at a certain period of time, but to have information about their utilization, movement (enter/exit ward), and inter-service transfers. The information collected allows hospital administrators and equipment manager to have a global vision of the utilization of their equipment park. For instance, the system registers provides information on the total utilization "in days" of each pump used in ward A and/or ward B during the pilot project. From the analysis of these data a variation on the total days in use of the RFID-enabled infusion pumps can be noticed, with some pumps having a higher utilization rate than others.

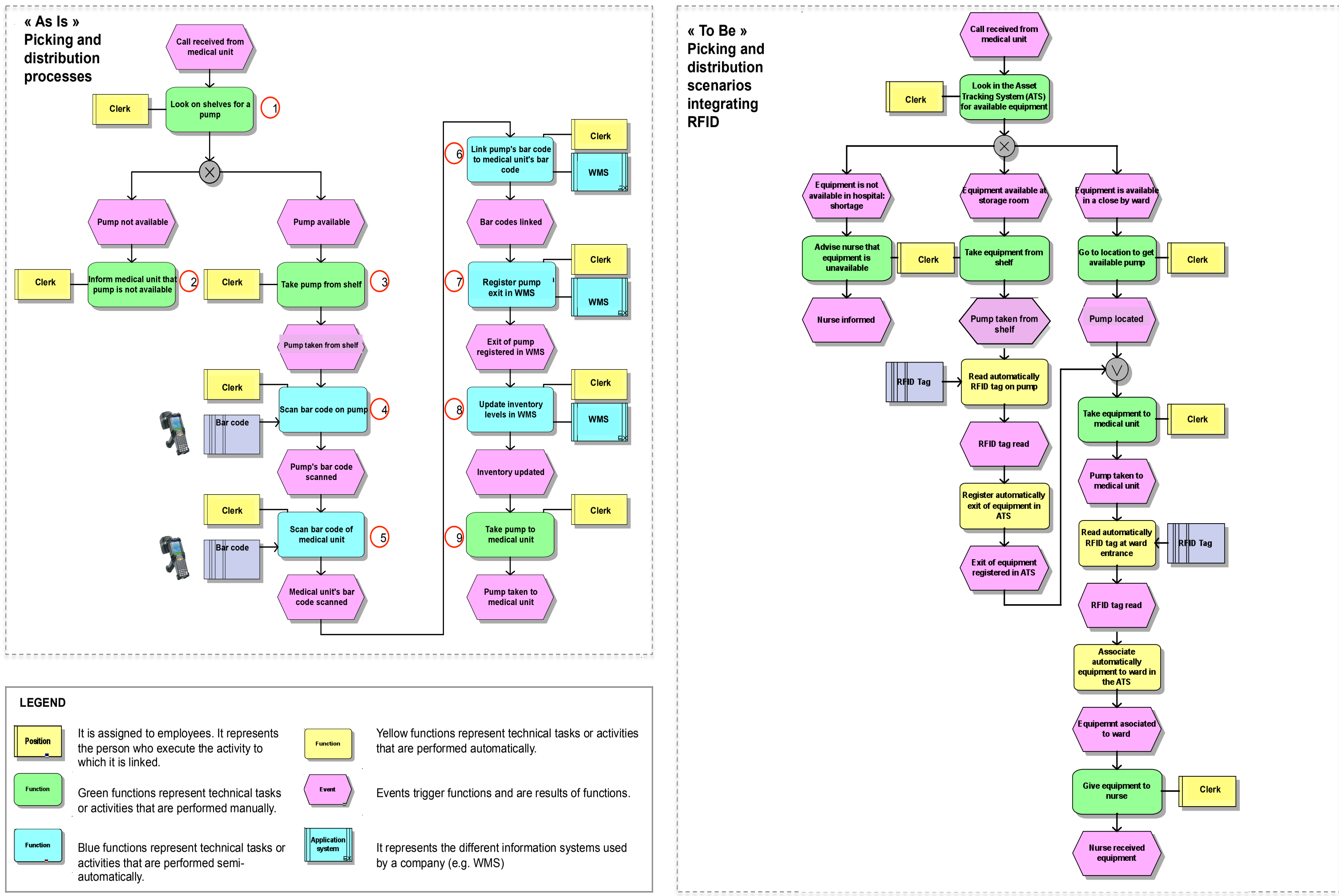

Figure 5-4 Gap analysis: As Is vs To Be picking and distribution processes

Table 5-4 RFID-Enabled Asset Management: Main Kpis

KPI LEVEL	KPIS AND MEASURE ORGANIZATIONAL GOAL
Essential KPIs: Quality of healthcare service	KPI-1: % of patients needing to be assigned an IV pump. Measured as the percentage of patients needing to an IV pump relative to all patients within measurement period. KPI-2: % of patients being assigned an IV pump. Measured as the percentage of patients being assigned an IV pump relative to all patients needing an IV pump within measurement period. KPI-3: % of patients needing to be assigned an IV pump, but not being assigned one.
Primary KPIs	KPI-4: % of available infusion pumps in the central storage room at a given time. KPI-5: % of time that one particular IV pump is available in the central storage room at a given time. KPI-6: Average % of time that IV pumps are available in the central storage room at a given time. Measured as average time that infusion pumps are in inventory. KPI-7: % of available IV pumps. Measured as the percentage of IV pumps not in used relative to all available IV pumps. KPI-8: Average utilization/usage time of IV pumps. Measured as the average time (e.g. in hours) that IV pumps are used. KPI-9: Average non-stop utilization/usage time of IV pumps. Measured as total hours of IV pumps non-stop usage. KPI-10: % of IV pumps in use in each ward at a given time. Measured in terms of total IV pumps used at a specific ward at a given time. KPI-11: Projected vs actual IV pumps utilization/usage. Measures of how well the utilization of pumps can be predicted. KPI-12: IV pump's transit time. Measured by the number of minutes (or hours) from the time an IV pump leaves the central storage room to the time it arrives at the ward. KPI-13: IV pumps stock-outs per period. Measured as the number of times where a demand cannot be met due to the absence of the required inventory. KPI-14: % of IV pumps incorrectly located. Measured as the percentage of IV pumps incorrectly located relative to all IV pumps. KPI-15: % IV pumps shrinkage. Measured as the percentage of IV pumps that cannot be accounted for inventory. KPI-16: IV pump's inventory accuracy: physical stock against system stock. Measured in terms of the accuracy in IV pumps physical stock against system stock. KPI-17: Value of IV pumps stolen from inventory. Measured as the monetary value of IV pump stolen from inventory. KPI-18: IV pumps inventory value. Measured as the monetary value of IV pump total inventory. KPI-19: % of IV pumps transferred between wards. Measured as the percentage of pumps being moved between wards. KPI-20: % of IV pumps returned to storage room after usage. Measured as the percentage IV pumps returned to the storage room relative to all IV pumps assigned to the ward within measurement period. KPI-21: Average number of IV pumps requested by a specific ward during a given period.
Other Critical factors	KPI-22: Customer satisfaction level (ward) KPI-23: Staff morale (clerks, nurses, doctors) KPI-24: Improved work environment KPI-25: Enhanced eemployee motivation KPI-26: Inter-units relation KPI-27: Storage room image and reputation KPI-28: Hospital good image and reputation KPI-29: Improved organizational teamwork KPI-30: Technological edge KPI-31- Improved communication and control KPI-32: Improved management of information about assets (infusion pumps) KPI-33: Improved accuracy of decisions KPI-34: Improved patient satisfaction KPI-35: Intellectual Capital

Table 5-4 presents core KPIs related to receiving, put away, picking, distribution, restocking, and usage activities within the context of medical equipment management were analyzed. Being able to measure these metrics is of chief importance for material managers and hospital stakeholders since it will provide them with the necessary information to evaluate the whether their clinical critical assets are utilized, maintained and manage at the levels necessary to ensure operations productivity and well as quality care delivery. However, the relative importance of these KPIs widely differs between the different stakeholders. For instance, the manager of one of the wards stated that “after all, the most crucial objective is to know the location of the infusion pumps”, discarding at the same time the importance of some previously agreed objectives (phase 1) such as operational issues such as keeping up-to-date equipment status on maintenance, sterilization, or decontamination and administrative issues such as overbuying, unnecessary rentals, under-utilization of hospital assets and elimination of costly replacement of lost or stolen medical equipment.

The analysis of KPIs also revealed that the nurses did not systematically register the status of the infusion pumps that they use. The information on pumps utilization, from the moment it is assigned to the patient to the moment it is not in use any longer, is therefore inadequate in some cases. Nurses and other participants then envisioned a technological solution where the RFID tags would be an integrated element of the medical equipment, so that information could be collected flawlessly.

5.5.6 Conclusion

The palpable paucity of established and structured RFID implementation frameworks to guide healthcare managers led us to propose a five-phase implementation model. The results presented in this paper offer valuable insights for top managers in hospitals and IT specialists responsible for RFID implementation.

First, the detailed longitudinal field research allows us to document the prevailing issues related to RFID implementation in a hospital setting. The most significant issues are not technological but are mainly organizational, as they seem to arise from the presence of diverging perspectives.

The empirical evidence presented in this paper demonstrates a cleavage between the administrative and clinical perspectives but also within the clinical perspective. However, divergences also run deep within each perspective (for instance, nurses vs. doctors) and between the technologists in the hospital (ICT managers, biomedical engineers, and maintenance specialists) and the administrators. It is therefore critical to better understand these organizational issues and, for managers and IT specialists, not to underestimate them.

Second, empirical evidence shows that the process of RFID implementation is indeed highly iterative. Participants revisited and modified previously agreed steps. For instance, the benefits assessment and the analysis of KPIs (phase 5) led to reconsider the stated objectives (phase 1) and the retained technological scenario (phase3). Such iterations, although inevitable, are also time-consuming. By carefully assessing all implications of each phase on subsequent phases, some iteration may be prevented.

Third, the results also prove that benefits are derived from RFID implementation. The new RFID-enabled processes provide information on assets availability rate, utilization rate, and real-time localization. Information on asset status could however be improved, either by increasing the nurses awareness to the new technology or by integrating RFID tags in the design of infusion pumps. Both options may require some time. KPIs represent an effective tool to formally evaluate and assess the benefits derived from RFID implementation.

RFID represents a new paradigm for asset management in healthcare. It increases in productivity through elimination of search delays from the staff and impacts the care dimension. Indeed, accessibility to critical resources allows care professionals to respond more efficiently and faster to clinical events, and therefore improves patient care and the patient experience. Other strategic objectives targeting cost effectiveness can be as well be derived from such implementation thanks to a potential reduction of overbuying and or replacement, unnecessary rentals, and under-utilization of hospital assets.

Acknowledgment
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CHAPITRE 6 ADDING INTELLIGENCE TO MOBILE ASSET MANAGEMENT IN HOSPITALS: THE TRUE VALUE OF RFID[3]

Abstract

RFID (Radio Frequency Identification) technology is expected to play a vital role in the healthcare arena, especially in times when cost containments are at the top of the priorities of healthcare management authorities. Medical equipment represents a significant share of yearly healthcare operational costs; hence ensuring an effective and efficient management of such key assets is critical to promptly and reliably deliver a diversity of clinical services at the patient bedside. Empirical evidence from a phased-out RFID implementation in one hospital demonstrates that RFID has the potential to transform asset management practices in hospitals by reducing existing inefficiencies and by allowing the emergence of intelligent processes. Adding some level of intelligence to mobile asset management processes is undoubtedly the most important benefit that could be derived from the RFID system. Results show that the added intelligence can be rather basic (auto-status change) or a bit more advanced (personalized automatic triggers). More importantly, adding intelligence improves planning and decision-making processes.

Keywords: *mobile assets management, RFID; inefficiencies, intelligent processes, added-intelligence, hospitals.*

6.1 Introduction

Many hospitals in developed countries offer specialized and quality healthcare. They are usually equipped with modern, up-to-date and sophisticated medical equipment such as positron emission tomography scanners or magnetic resonance imaging equipment. They are considered as rather innovative in terms of medical procedures and adoption of medical equipment. However, they are viewed as 'laggers' when it comes to the adoption of information and communication

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technologies (ICTs), in comparison with other industries [1]. In fact, ICTs initiatives in healthcare have typically not been a priority and have experienced a considerable rate of failure [2] due to several factors such as financial and technological issues or clinical staff resistance [3-5].

ICTs are perceived as a powerful tool to support organizations in the healthcare sector and could reduce costs by streamlining complex lengthy administrative and clinical processes [6]. This is indeed a crucial concern since these processes are 'full of waste and inefficiency' [7]. In fact, hospitals operate for the most part with unstructured processes and disrupted workflows. They have been characterized as inefficient, complex and unpredictable systems [8]. Caregivers and other staff are regularly discouraged by the recurrent problems that they encounter while performing their daily work [7,9].

Many researchers agree that the adoption of ICTs is critical to enhance the quality of healthcare, reduce medical errors, contain expenditures, and comply with governmental requirements [10,11]. According to banks et al. [12], the internet and wireless technologies create the required digital environment for applications such as electronic health records systems, physician order entry systems, electronic prescribing or radio frequency identification (RFID)-enabled solutions. This paper focuses on RFID technologies that are expected to play a vital role in the healthcare sector [13-15], and investigates the potential of RFID for improving the management of mobile assets in hospitals. Mobile assets are here defined as movable medical equipment and devices; they include infusion pumps, telemetry units and other medical equipment. The specific objectives of this paper are twofold. First, we will assess how RFID could reduce the existing inefficiencies related to mobile assets management, in particular those related to the management of infusion pumps. Second, we will attempt to demonstrate that RFID allows the emergence of intelligent processes. Both objectives are pursued by analysing empirical evidence from a phased-out RFID implementation in one hospital.

This line of inquiry seems pertinent for several reasons. First, medical equipment represents a significant share of healthcare costs. Worldwide expenditures on medical equipment and devices rose from us$145 billion in 1998 to us$220 billion in 2006 [16]. In the U.S., spending on medical devices totalled $156.3 billion or 6.0 percent of total national health expenditures in 2010 [17]. In particular, the cost burden associated with the acquisition and management of mobile assets is rising steeply. These assets represent about 95 percent of hospitals' clinical asset park: thousands of mobile assets are circulating in hospitals, representing millions of dollars in capital and operating expenditures [18]. Second, the number of clinical devices needed at the patient bedside is increasing. According to Stewart [18], the number of medical devices needed to treat each patient has increased by 62% over the past 15 years, reaching 13 devices per hospital bed in 2010. For instance, American hospitals are currently using an average of two infusion pumps at the patient bedside [19]. This situation increases acquisition budgets and maintenance costs. Despite much effort, the average utilization rate per year of mobile equipment is only 42% [19, 20]. Third, medical equipment is used daily for a wide variety of diagnostic and therapeutic services to patients [21]. The availability of mobile assets is critical, especially in life-threatening situations. However, with thousands of medical portable equipment devices moving around the hospital, the management of these mobile assets is, without an automatic tracking and tracing system, very problematic.

The remainder of the paper is organized as follows. The next section provides a brief introduction to RFID technologies and components, and introduces the main facilitators and barriers to their adoption in this industry. Then, we will outline the research design and describe a proof of concept (POC) within a hospital environment. The results of the field study carried out in a hospital in the Netherlands will be presented in the fourth section. Finally, some concluding comments will be made in the last section.

6.2 Background

6.2.1 RFID technology

RFID technology belongs to the class of automatic wireless identification and data acquisition technologies [22, 23]. RFID uses radio-waves to accurately and automatically identify physical entities—i.e. objects, animals, or individuals—without human intervention, using a radio-frequency (RF) transmitted identification code [22, 12]. Unlike barcode technology, RFID allows a unique physical entity to be identified, and multiple tags to be read simultaneously. An RFID system is composed of three main components: the RFID tags, the RFID readers and the RFID middleware (left side of Figure 6-1).

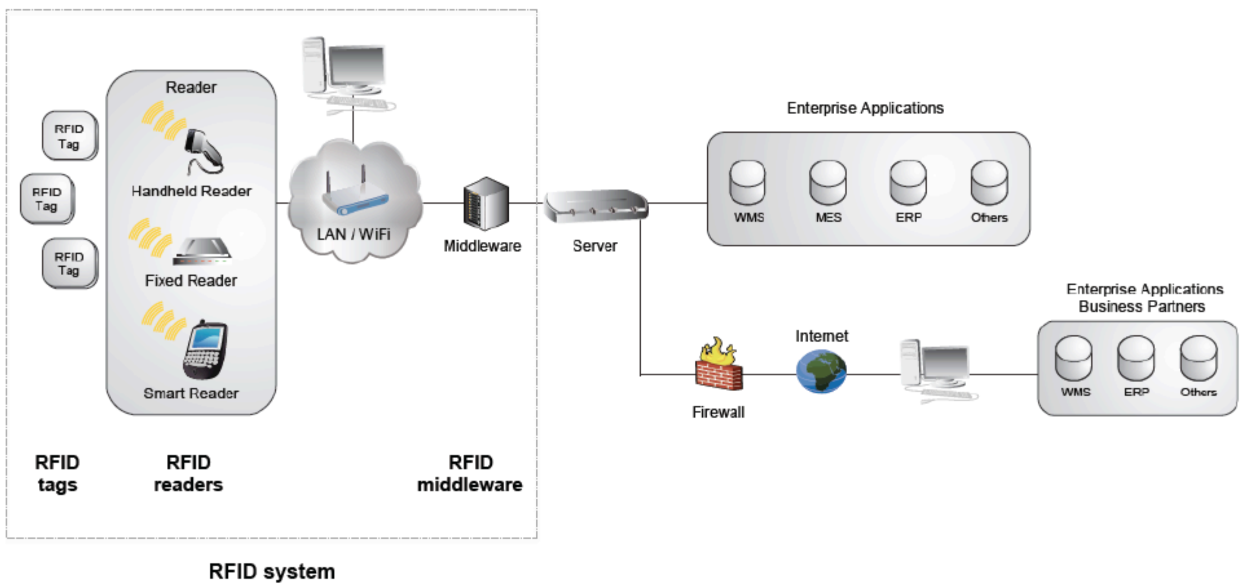

Figure 6-1 RFID system infrastructure

RFID tags are composed of electronic circuits and antennas, which communicate data to readers via electromagnetic radio waves permitting no-line-of-sight communication [24, 25]. Depending on the entity to being tagged, different tag designs can be used. For instance, in healthcare, RFID tags come in various formats, including badges, pendants, labels, wristbands, cards and even implants [26]. RFID tags can be classified based on a wide array of features such as memory type, operating frequency, power source, design, etc. With respect to their memory capabilities, RFID tags can be categorized as read only (RO), write once/read many times (WORM), and read/write (RW). The latter allows users to read and record data on the electronic circuit as tags rotate within a facility or move along a supply chain [27, 28]. Depending on their power source, RFID tags are mainly classified as active or passive [24, 29]. Active RFID tags are equipped with an on-board battery to support reader-tag communication, whereas passive RFID tags do not have an internal power source and consequently draw their power from the reader's RF electromagnetic field [29]. RFID tags can work at low frequency (LF), high frequency (HF), ultra-high frequency (UHF), and microwave (μWave), determining their transmission ranges.

Passive tags have a shorter read range, but they are far less expensive than active tags [24, 29]. Active tags have better data transmission rates given their enhanced reading and writing range and speed capabilities, usually beyond 100 meters [29]. They also have higher data storage capacity, permitting the storage and transmission of a fairly large amount of additional information besides its unique identification code, and offer the possibility of integrating sensors and actuators to allow monitoring of some environmental parameters such as temperature and humidity [28, 29]. Given that active RFID tags are less affected by environmental factors than passive tags are, they tend to be selected to track, trace and locate valuable assets or people, such as clinically critical mobile medical equipment, or psychiatric patients [27, 30]. Initially, the majority of active RFID technologies were proprietary; however, current active RFID systems can work over other wireless standards including Wi-Fi (IEEE 802.11 a,b,g,n), ZigBee (IEEE 802.15.4), Bluetooth, and Ultra Wide Band (UWB) (IEEE 802.15.4).

The RFID readers or interrogators are responsible for capturing and transferring the data stored on the RFID tags to the RFID middleware. RFID readers come in different formats, ranging from hand-held, fixed, and smart readers, to vehicle-mount readers and more. Furthermore, RFID readers can read RFID tags speedily (in less than 100 milliseconds) and allow multiple-tag readings [31]. The RFID middleware filters, processes, manages and aggregates the vast amounts of data collected by the readers from the embedded RFID tags. It then routes the required data to the enterprise applications [32], within one organization or among its business partners (right side of Figure 6-1).

6.2.2 Major issues related to RFID deployment in health care

Healthcare should be 'the next home for RFID' [33] since RFID potential could generate key benefits such as improvement in patient safety, reduction of medical errors, and optimization of core business processes [5, 33-35]. Even though RFID is at the early stage of diffusion in the healthcare sector, it has been recognized to have the potential to provide patient identification, medical equipment tracking, inventory management, medications management and dosage validation, staff management, as well as to help medical professionals 'keep tabs on their patients' in real time [34, 36]. In spite of the awareness of RFIDs' potential benefits for healthcare, the majority of hospitals are still taking a 'wait-and-see' approach since various issues are still limiting its adoption and implementation, including the high cost of the infrastructure, some technical issues, and several prevailing privacy and security concerns, among others [25, 30, 37, 38].

High cost of infrastructure

RFID implementation requires a major investment; this does represent a significant roadblock to a widespread diffusion of healthcare RFID applications [25, 39, 40]. In order to reduce implementation costs, some hospitals are 'piggybacking' by using an existing Wi-Fi network for tracking applications. However, this means that signals from RFID tags may not be as accurate, since they have to 'compete for space' with other communication devices present at the facility [41, 42].

Technical challenges

Technical challenges correspond to another barrier to broader RFID diffusion in healthcare. Problems related to the reliability and interoperability of RFID technologies, interferences with other clinical systems or medical devices, and the lack of industry standards need to be addressed [25]. According to Fisher and Monahan [43], one important issue affecting RFID in a hospital context is the fact that vendors do not properly ensure RFID system compliance with current medical regulations. The issue of potential electromagnetic interference caused by RFID system deployment within hospital environments has to be further investigated. In the Journal of the American Medical Association, Van der Togt et al. [44] stated that RFID could induce 'potentially hazardous incidents in medical devices' used in healthcare facilities. Although the US Food and Drug Administration (FDA) has not yet reported adverse incidents directly caused by electromagnetic interference with medical devices, it considers that it is important to evaluate whether or not RFID could have an impact on medical devices' performance [45]. Further research in this area is crucial as potential electromagnetic interference could inhibit the spread of

RFID technology until total compliance with the applicable regulations is demonstrated.

Another issue is affecting RFID deployment. Assuring interoperability with the existing infrastructure is one of the main concerns of healthcare organizations [46]. In order to integrate RFID with the existing hospital information systems or other back-office systems, it might be necessary to re-engineer some of the existing legacy systems [37].

The lack of standardized RFID protocols is also slowing down RFID adoption in the healthcare industry [25]. Although the International Standards Organization (ISO) and the Electronic Product Code Global (EPCGlobal) have generated an extensive set of standards for RFID applications within the specific industrial sectors, there is still a palpable lack of standards governing the use of RFID in healthcare [47]. Consequently, hospital administrators do not want to take the risk of investing in RFID until it reaches a certain maturity level and until standards are compatible with existing ones [43]. However, the growing number of opportunities is driving the development of standards and guidelines. In particular, RTLS (real-time location systems) have driven the emergence of localization standards, such as the ISO/IEC 24730 standard. This standard provides guidelines concerning air interface and application programming interfaces when using active 2.4-GHz RTLS technologies, for instance in asset management applications [48].

Privacy and security concerns

It has been stated that RFID could lead to the rise of a surveillance society [49], generating concerns regarding privacy and identity security, particularly in complex environments such as healthcare facilities where patients information, including patients medical records should be kept confidential [38]. RFID's unique capabilities to store data about patients and staff raise privacy-related concerns among hospital administrators, patients and personnel; as a result, some hospitals have delayed the use of RFID while they wait for these issues to be dealt with [38, 43]. Hospitals need to ensure that all systems implemented in their facility comply with existing federal privacy protections as mandated under the Health Insurance Portability and Accountability Act [43].In fact, a secured RFID system will make sure that issues regarding confidentiality, unforgeability, location privacy, and scalability are taken into account [38]. A variety of methods can be used to increase data security while deploying a RFID system in the healthcare arena, including killing, shielding, locking and re-encrypting tags, among other things [36]. In the context of healthcare security and privacy concerns with regard to storing personal and medical data in RFID tags

Organizational issues

RFID integration may entail substantial process redesign, affecting the way personnel perform their work. Resistance to change could be a major drawback to the successful accomplishment of the implementation [50]. This is an area of high concern when implementing RFID in professional bureaucracies. Mintzberg [51] qualified hospitals as professional bureaucracies, which are characterized as being complex, rigid, and highly conservative organizational structures with a low degree of coordination and innovation. These characteristics may constitute roadblocks to innovations and ICTs projects [52], including RFID applications. In fact, clinical professionals may perceive technological innovations as a threat to the autonomy, status, institutionalized values and beliefs that are attached to the nature of their profession, potentially triggering their resistance to such change [53].

6.2.3 RFID and Added Intelligence

RFID has the potential to transform management practices and promote workflow optimization. It is also regarded as a technology enabling the transformation of everyday objects into ‘intelligent’ or ‘smart’ objects, and in the context of this article, into ‘smart assets’ [54-58]. When equipped with RFID tags, these physical objects gain new capabilities permitting them to have a unique identity, store data, sense their environment, and in some cases - depending on the application - display pertinent information such as their features, history, etc. More importantly, RFID-enabled smart objects communicate with humans and help them to make more appropriate decisions about their management, automatically triggering ‘intelligent business processes’ and facilitating the integration of distributed intelligence applications in daily life [54, 58-61]. Consequently, RFID is perceived as the missing link between the ‘physical product’ and the ‘virtual product’, increasing the use of information, and knowledge all along the product life cycle, since information travels seamlessly with the RFID-enabled smart product [62, 63].

RFID may be one of the building bricks for ambient intelligence (AmI) [55, 64]. AmI is a rising IT concept, which envisions an environment "where technology will become invisible, embedded in our natural surroundings, present whenever we need it, enabled by simple and effortless interactions, attuned to all our senses, adaptive to users and context and autonomously acting" [65]. AmI is characterized by the presence of systems and technologies that are embedded, context aware, personalized, adaptive, and anticipatory [64]. RFID technologies are most likely one of the key technologies that will facilitate AmI applications since it fosters the presence of 'invisible intelligence' through RFID-enabled objects.

6.2.4 Intelligent asset management in hospitals

Mobile asset management is problematic in hospitals. These assets are daily lost, misplaced or even stolen. RFID offers the capabilities for real-time tracking and tracing of medical equipment that "provide a direct increase in clinical efficiency while also reducing cost" [15, p.110]. The main thrust of this paper is that RFID may also add some level of intelligence to mobile asset management in hospitals.

"However, the reality of RFID adoption in healthcare is far behind earlier expectations" [66, p.3507]. One might wonder whether RFID is really suitable for reducing operational inefficiencies affecting the key processes of mobile asset management in hospitals. Would RFID enable the emergence of intelligent processes that would ensure a more adequate management of mobile medical equipment? In this article, we intend to further investigate this line of inquiry.

6.3 Research design

A research design implies making plans and decisions about the strategy of inquiry, the unit of analysis, the research site, the informants, the data collection methods and data analysis, and the validation of research [67].

6.3.1 Inquiry strategy

The vast majority of journal articles concerning RFID adoption present empirical studies conducted in the context of manufacturing or in retail supply chains. However, RFID adoption in the healthcare sector, especially in hospital settings, remains under investigated [23, 66]. This represents a key starting point and the chief motivation for our research, which aims to improve our understanding of the ability of RFID technology to improve mobile asset management in hospitals. An exploratory initiative therefore seems an appropriate strategy of inquiry [68].

Action research has been considered as a multidisciplinary, valid and widely accepted research strategy [69]. It has more recently raised increased attention from researchers in information systems [70, 71]. Hence, this approach seems particularly suitable in the context of this research.

6.3.2 The unit of analysis

The research focuses on the processes related to mobile asset management, more specifically those associated with one type of mobile asset, namely digital or electronic infusion pumps (named "IV pumps" further on in this paper). The unit of analysis is thus the process. A process-based approach allows "a more dynamic description of how an organization acts" [72, p. 2]. Moreover, the process view allows organizations to move away from traditional functional structures and focus on value creation. It creates a "strong emphasis on how work is done within an organization" [72, p. 5]. According to Murphy [30], "only when an organization fully understands its business processes can RFID be truly effective".

Digital IV pumps deliver medications to a patient's body in a "controlled, precise, and automated manner" [74, P. 2]. They are not the most expensive mobile assets in hospitals, but 90 per cent of patients are treated with these medical devices during their stay in the hospital [75]. In fact, IV pumps are critical for daily healthcare services and become essential in life-threatening situations. Digital IV pumps need to be carefully monitored as some adverse-related events may occur [74]. In particular, the awareness of product recalls and the required maintenance (preventive and reactive) constitute areas of concern in hospitals.

6.3.3 The research site

The research took place in a 630-bed university-affiliated general hospital. Healthcare services are offered in some 30 medical units (including intensive care, cardiology, orthopaedics, surgery, gynaecology, paediatrics, geriatrics, etc.). The hospital uses various business applications such as a maintenance management system (MMS) and a warehouse management system (WMS) to manage asset inventories, maintenance and repair. The hospital relies on bar code systems to identify most assets and update inventories. Almost 100% of the hospital (slightly more than 300,000 square-feet) is Wi-Fi enabled. A telemetric system is also deployed for patient monitoring.

For building the technological scenario, an RF fingerprinting of specific areas in the hospital was undertaken using a Rohde & Schwarz FSH6 spectrum analyser to measure possible interference and Wi-Fi coverage in specific areas. Special attention was paid on leveraging the existing legacy systems (information systems, Wi-Fi infrastructure, bar code, etc.) and detailed evaluation of different technological scenarios was performed by key informants (see next section). At the end-of the pre-feasibility phase, participants decided that the RFID application would be limited to one type of mobile assets (digital IV pumps) and to three units in the hospital. The RFID application would be implemented as a proof-of-concept and, depending on its success, could be extended to other mobile assets and other units.

The retained technological scenario is as follows: Wi-Fi-based RFID active tags are embedded in the digital IV pumps. A push button is incorporated to the tags in order to provide additional functionalities, for instance, to record the status of the pump—e.g. in use, not in use. The tags are read by RFID exciters at choke points, namely at the central storage room and at the entrances to two medical wards. The RFID tags are spotted as they pass within exciter range; once the tag is activated, it is able to transmit its ID number, which is received by standard Wi-Fi access points from a leading WLAN vendor supplier. The captured data is transmitted to a location engine platform for analysis and the asset tracking engine calculates tag locations by processing data from the tags and various Wi-Fi access points. During the installation of the RFID-enabled platform, a tag positioning test was undertaken to identify the best RFID tag position, to ensure that tags would be readable and would not interfere with equipment handling and usage.

6.3.4 Key informants

Participation of multiple informants is highly appropriate to ensure reliability of data collected. The key informants are either from the hospital (the research site) or from 8 external organizations (one national association, four technology companies, one research centre and two universities). Figure 6-2 shows the overall distribution of key informants.

From the hospital

Key informants are from the clinical and the non-clinical units. Eight clinical professionals participated in the research: two head nurses, two ward managers (one medical specialist and one physician) and four team managers. The director of the hospital was an active participant and played a decisive role in the project, for instance giving the "go" to continue with the project at the end of the pre-feasibility phase. Non-clinical professionals include the manager of the technical department, two biomedical engineers, two managers from the ICT department and one technical expert. Two clerks working in the storage room provided valuable inputs.

From outside the hospital

Eight key informants, including top managers, technical experts and professionals from 4 private firms participated in the project. Finally, the chairman of the national association, a specialist in facility management, was closely associated with the RFID project for the two-year period.

Five university-based researchers, including the director of one research centre, played multiple roles from passive participants (on-site observations) to active participants (elaboration of different technological scenarios). In line with action research, they work collaboratively with all key informants in all five phases of the RFID project. They also provided inputs and expertise, and are therefore considered here as key informants.

In addition to the thirty-one key informants, many people, especially inside the hospital, gave punctual information and detailed explanations, but are not represented in Figure 6-2.

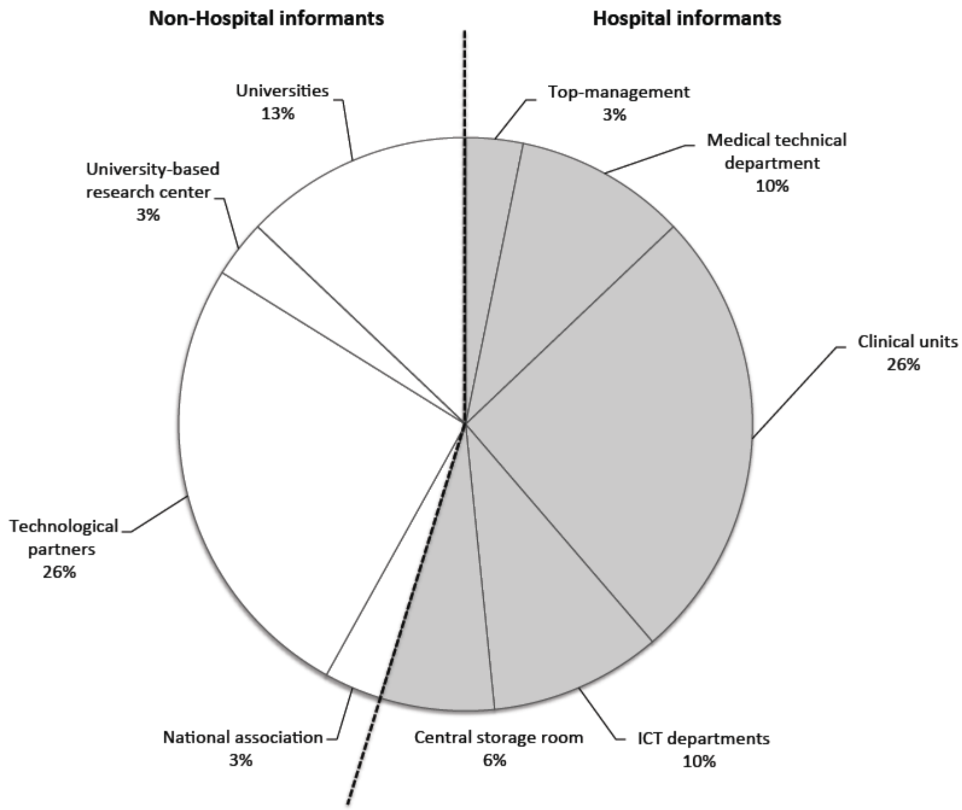

Figure 6-2 Profile of key informants

6.3.5 Data collection methods, data analysis and validation

Empirical data was collected during two years, from the original intention to consider RFID to improve mobile asset management in the hospital to the post-implementation phase. Data was recorded, analysed and validated for each of the five main phases of the RFID project, namely pre-feasibility, feasibility, RFID scenario-building and validation, implementation in a real-life setting and benefits assessment [59].

Data collection methods

We relied on multiple data collection methods, including:

i) Internal documents (hospital directives, procedures, etc.) and external documents (healthcare reports, guidelines, etc.);

ii) Semi-structured interviews with key informants and focus groups;
iii) On-site observations of hospital facility;
iv) Raw data from the RFID system such as IV pump transfers, movements and status.

Systematic analyses of both quantitative and qualitative data were conducted during the two-year period. Data was thoroughly cross-validated within and between each of the five phases of the RFID project. In particular, process mapping based on a drill down approach proved to be a powerful visual tool to analyse empirical data, to confirm the exactitude of observations and comments, to anchor discussions during the interviews and the focus groups, and to improve decision-making.

6.4 Discussion and results

6.4.1 Analysis of the current situation

The participants agreed to focus on three main sets of activities that are considered as particularly crucial for improving infusion pump management, namely warehousing, usage, and maintenance activities. Figure 6-3 presents these activities and their related processes, and displays the flow of infusion pumps. It can be noted that the flow of these medical devices between the storage room, the medical wards and the maintenance department is iterative and is difficult to track in real-time.

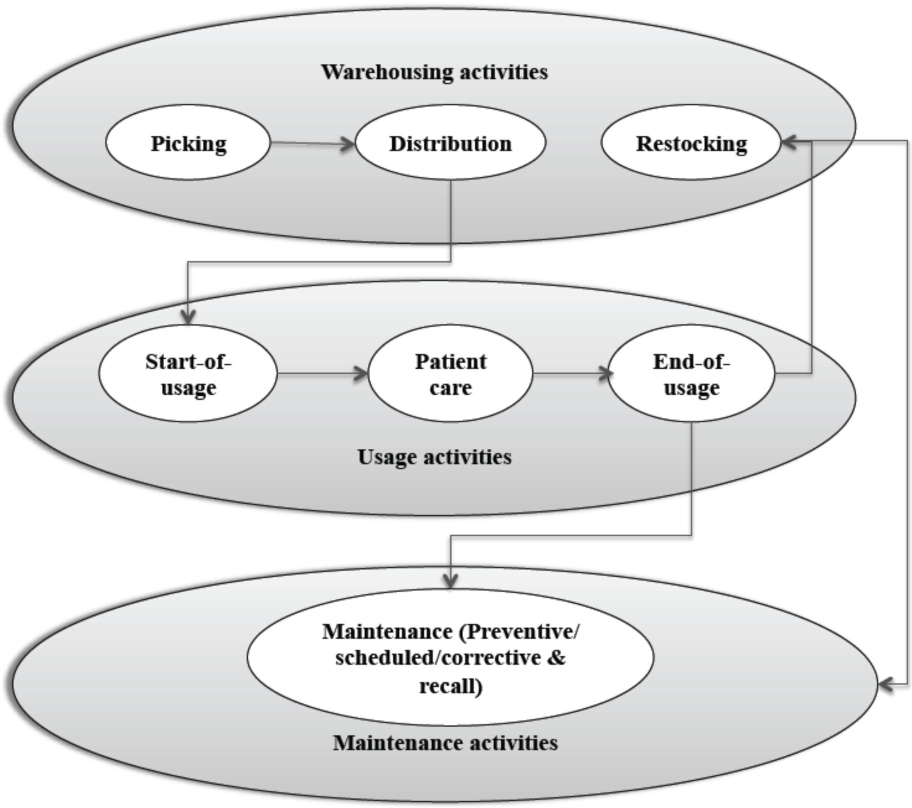

Figure 6-3 The management of infusion pumps: main activities and key processes

When asked to comment on the key processes presented in Figure 6-3, the clinical and non-clinical staff reached a consensus: this is far from being efficient. Their comments from the semi-structured interviews and from the focus groups, as well as outcomes from observation during the field study, pointed to one major problem, namely lack of real-time visibility that generates six major and interrelated inefficiencies affecting the management of infusion pumps (Figure 6-4). These inefficiencies are in decreasing order of importance: 1) inventory shortages, 2) asset sub-utilization, 3) waste of staff time, 4) service delays, 5) maintenance delays, and 6) information 'silos'. Inventory shortages were perceived as the most prevalent inefficiency (rank 1) whereas information silos were perceived to be the least important one (rank 6).

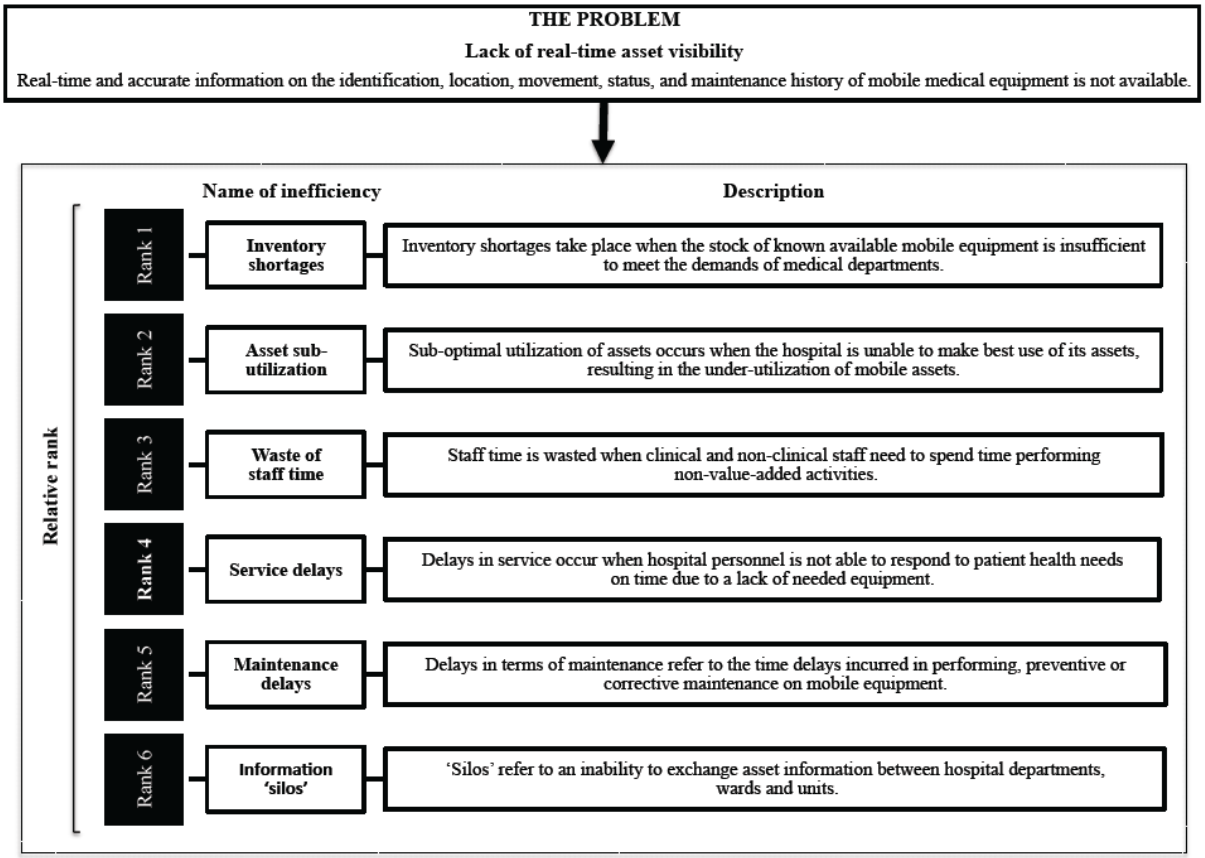

Figure 6-4 The management of infusion pumps: the problem and critical inefficiencies

6.4.1.1 The problem: Lack of real-time visibility

Barcodes are widely used at the hospital to identify IV pumps and manage inventories (the same applies to other medical equipment and devices) whereas a numeric label (here a simple four digit sticker) is retained for the management of maintenance activities. When IV pumps leave the storage room, the barcode on each medical device is read manually and the pump's information is retrieved. However, this is only performed at the storage room and there is no record of the whereabouts of the IV pumps in other areas of the hospital. The personnel cannot track IV pumps as they move through the hospital, neither when being used by clinical staff for patient care nor when being handled across the hospital by non-clinical staff such as warehouse clerks or biomedical engineers.

When pumps are unavailable in one unit or at storage room, the clinical staff will look into other units, take any pump available and keep it in their unit after they have treated the patient. As stated by a medical team leader “when the clinical staff do not need the pump for their patients, they usually won’t give it back to the unit that lent it to them because of various reasons: i) they want to keep it for themselves to make sure they have enough pumps the next time they need one, ii) there is no registered system that indicates from where the pump came, so it is very challenging, with the daily clinical staff shifts, to identify the unit that had originally lent the equipment, and iii) other medical units will act in a similar manner and they will not give pumps back after end-of-usage”. The actual location of the vast majority of pumps located outside the storage room is unknown at any given time. The participants concurred that the real problem is thus a severe lack of real-time visibility.

6.4.1.2 Critical inefficiencies generated by the lack of real-time visibility

Rank 1: Inventory shortages

The direct consequence of the lack of real-time visibility of mobile equipment is a frequent shortage of IV pumps in the central storage room. Indeed, we observed on many occasions that the designated shelf to store available IV pumps was completely empty. Consequently, storage clerks often struggle to comply with medical units’ demands for equipment. They face complaints and frustrations from nurses and doctors who consider the lack of available pumps to be a bottleneck in their daily activities. This situation not only affects the work environment and the quality and reliability of patient care, but it also entails significant economic impacts. In fact, inventory shortages result in high inventory cost, as more equipment needs to be bought or rented to cover for lost or unavailable ones. Some 30 pumps were ‘lost’ over the last few years, representing a 25% shrinkage rate and a loss of about €45,000 (the cost of each IV pump is about €1,500). The replacement and possible overbuying of mobile equipment is very costly for the hospital, and administrators are concerned about the share of yearly costs that it represents.

Rank 2: Asset sub-utilization

Since the shortage of IV pumps is a daily and on-going problem, it is common practice for the clinical staff to overlook the established standard procedures of returning unused pumps to the central storage room. Instead of advising storage room clerks that a specific piece of equipment is no longer in use and is ready to be restocked, they keep IV pumps in wards' closets and rooms in hopes of having one available when they need one to treat their patients. Clinical staff believes that if they give up a pump and return it to the central storage room, they will likely not be able to get one when they request one the next time. Thus, misplaced or hoarded IV pumps accumulate across the hospital and are not used for several hours or even days because no one, except maybe the person who stored or hid them, knows exactly where they are.

The perspective from the non-clinical staff on inventory shortages is slightly different from the one taken by the clinical staff. They are aware that pumps are often misplaced, hoarded or hidden around the hospital by clinical staff, and stress that clinical staff does not follow the procedures in place for the returns and transfers of equipment, and thus contributes significantly to the lack of asset visibility.

Rank 3: Wasted staff time

As mentioned by one project participant, 'If there is an influx of patients, there might not be any IV pumps in inventory in the storage room, so someone has to go and find the pumps'. However, manual searching for available IV pumps is a time-consuming activity that impacts the productivity of storage room clerks, biomedical engineers and nurses. According to hospital personnel, it could, in average, take up to an hour for hospital staff to find an IV pump, in case they find one. Such wasted time translates into labour costs, which at the very least could amount to 110,000 Euros per year. Hospital administrators feel that this amount is rather substantial. Moreover, the impact of equipment search time on patient care is not negligible. Indeed, the clinical staff is also particularly concerned because they 'sacrifice' valuable time to find the needed equipment, time that should be used to deliver care to patients. In fact, care providers assert that they need to have access to all necessary resources, including mobile assets such as IV pumps, in order to have control over their own work. Furthermore, this creates frustration among the clinical and non-clinical personnel, adversely impacting the work climate.

Rank 4: Health service delays in diagnosis and treatment

All participants agree that the hospital is responsible for responding promptly to patients' medical needs while ensuring the highest quality and the most reliable healthcare services. They do agree that healthcare providers rely on a wide range of moving medical equipment in order to deliver a variety of diagnostic and therapeutic services to patients, and that the lack of real-time visibility of mobile assets, and more specifically of IV pumps, generates delays in patient care. Tangible effects of such delays, such as the costs of a longer stay in the hospital, could be estimated; however the intangibles such as staff frustration, patients' dissatisfaction and even improper health care are crucial, but much harder to evaluate. The manager of the Medical Technical Department insists that delays are non-negotiable and that "medical equipment, such as IV pumps, ECG machines, and hospital beds, has to be efficiently allocated to departments so that patients can receive proper and prompt care".

Rank 5: Maintenance delays

In the current situation, IV pumps cannot be located efficiently; hence, biomedical engineers working in the maintenance department are not able to find IV pumps that need to be repaired, recalled or are due for a scheduled preventive maintenance. Consequently, they either wait until the required pump comes back to the central storage room or they perform a physical search across the hospital. The physical search could take anywhere from a few hours to several days, and maintenance activities are delayed. The personnel affected by maintenance activities points out that the manufacturer's protocol recommends regular preventive maintenance of the digital devices. They argue that faulty infusion pumps can lead to several problems, such as over- or under-infusions, or delayed treatments. In life-sustaining cases, these problems obviously have dramatic consequences; in most cases, the accuracy of these devices is vital to patients' recovery and well-being. They conclude that on-time regular preventive maintenance is essential for providing high-quality care and add that reactive maintenance prompted by any adverse incident should be immediate.

Rank 6: Information silos

Two systems are currently in place to identify and track medical equipment, including IV pumps, in the hospital. The first system consists of a sticker integrating a numerical ID, which is used only by the maintenance department to identify equipment in their maintenance management system. The second system uses barcodes that are only scanned when the IV pumps are checked out from or returned to the storage room. These two systems are not integrated. Furthermore, when the equipment is transferred from one ward to another, there is no record of inter-ward transfers and there is no appropriate paper-based tracking log. The information about the pumps locations and status is thus not integrated and synchronized, and cannot be accessed by all the concerned parties, resulting in information silos. Furthermore, the information is incomplete, outdated (even with a proper paper-based tracking log), and is not shared between all the parties involved. A real-time and accurate asset tracking and tracing system is "badly needed".

6.4.2 Adding intelligence into healthcare processes: The true value of RFID

Participants recognize that an RFID-enabled asset management system would basically solve the lack of real-time visibility of infusion pumps and remove to a large extent the existing inefficiencies. The proof of concept demonstrated that, once the RFID system was deployed, it had an impact on all the seven key processes presented previously in Figure 6-3. If we examine, for instance, the potential of integrating RFID in the end-of-usage process (Figure 6-5), we can make the following observations: i) by simply pushing a button, nurses can report in an easy, timely and semi-automatic manner when an individual piece of equipment is no longer in use; hence, it is ready to be restocked and used by other staff, ii) the asset management system is automatically updated regarding the status of equipment (available), and iii) warehouse clerks could be automatically advised that the equipment is now available; they can take actions to restock the storage room or bring it to the biomedical department where biomedical engineers will undertake needed maintenance tasks. Levels of inventory are thus higher in the storage room and it is now possible to better respond to clinical demands, possibly eliminate shortages and perform the required type of maintenance in a more timely manner.

Figure 6-5 basically illustrates, for one key process, how the implemented RFID system works. But, is there any potential to add intelligence to the existing processes? Does RFID offer more possibilities beyond the mere identification, tracking or tracing tasks? Table 6-1 offers some answers to these questions.

The left side of Table 6-1 shows new RFID-enabled processes for the three main sets of activities required for the management of digital IV pumps in the hospital: warehousing, usage, and maintenance. The right-hand side categorizes the elements of added intelligence.

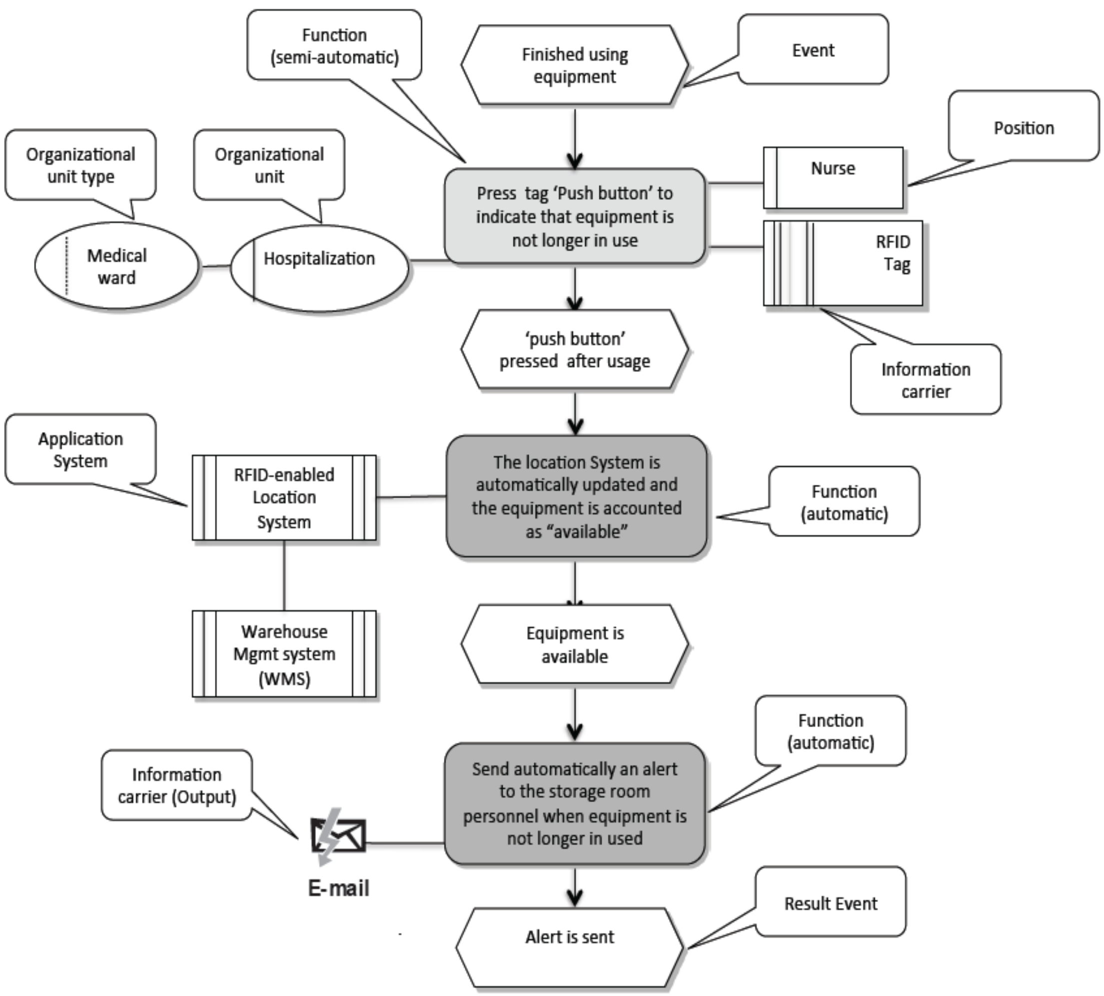

Figure 6-5 The RFID system and key processes: the case of end-of-usage process

Several interesting observations can be made from the real-life context of this RFID project:

1) The 29 processes presented in Table 6-1 are automated and reflect one well-known capability of RFID systems: auto-identification. Each RFID-enabled pump is uniquely identified, is context-aware due to the presence of exciters, and communicates with its environment. In fact, the RFID system is embedded in the hospital's electronic environment, as the only visible interface of the RFID system are the push-buttons. Several processes (for instance, P6) allow for auto-verification (i.e. verification with an existing system
2) Some processes (P14, P17, and P27) automatically change the status of the RFID-enabled pump: in use/ not in use, or in maintenance. The *auto status change* means that one knows in real time if a pump is available (for the RFID system, "available" implies not used, and not in maintenance). If the pump is available and its exact location is given, it can easily be located and assigned in a timely way to a patient. If the pump is not available, its status (used, in maintenance) and its location are confirmed.
3) Besides capabilities to automatically update WMS's pump inventory, for instance, after removing pumps from smart shelves (P3) or after automatically registering their exit from the storage room (P5), the RFID system could provide some automatic triggers that could be personalized. For instance, if the inventory of available pumps is too low, an alarm could be sent to the maintenance team to speed up their activities (P6), an automated security alert could be sent to inform designated staff that a particular pump is leaving the hospital, preventing unauthorized removal of equipment and theft (P29).

   The probabilities of errors or missteps could also decrease. For example, if a pump is under a manufacturer's recall, it could be located immediately and removed from inventory before any malfunctioning occurs. These automatic triggers make "real-time sense" and may be considered as adaptive during different events.

4) Real-time data from the RFID system could support daily decision-making for improving mobile asset management (P1, P8, P14, P15, P16, P17, P18, P22, P23, P24, P26, and P27). The RFID system also offers the necessary data to analyse the fluctuations in demands for pumps, their use, their availability, etc. (P4, P5, P7-P14, P17, P19-P22, P25-P29). By adding simple rules in the middleware, it could back up some goal-setting

directives, such as determining that at least 5 % of pumps should be available at any time. This was suggested by some participants, but not retained in the current scenario.

Table 6-1 demonstrates that the RFID system definitely adds automation to mobile asset management in the hospital and does, to a certain extent, add some level of intelligence such as auto-identification, recording and managing information, communicating with its environment, and demanding specific services or actions from hospital staff.

Table 6-1 Emergent intelligent processes (Ps) with the RFID mobile asset tracking system (Cont.'d)

New processes with the RFID mobile asset tracking system	Adding intelligence to processes
Warehousing activities	Each RFID-enabled pump allows:
- Picking	
P1: Locate automatically available equipment in the RFID-enabled-Mobile asset tracking system	– auto-identification; support decision-making; help planning
P2: Automatically read RFID tag as equipment is removed from *smart shelf* at storage location	– auto-identification; auto trigger-related necessary processes
P3: Register automatically the removal of equipment from smart shelf in the RFID-enabled-Mobile asset tracking system	– auto-identification; auto trigger-related necessary processes
- Distribution	
P4: Automatically read the RFID tag when the equipment leaves the storage room	– auto-identification; auto trigger-related necessary processes
P5: Automatically register the exit of equipment in the RFID-enabled-Mobile asset tracking system	– auto-identification; auto-verification; auto trigger-related necessary processes
P6: If inventory levels are too low at storage room, automatically send an alert to the maintenance team to speed up their activities	– auto-identification; auto-verification, auto trigger-related necessary processes
P7: Automatically read the RFID tag at the entrance of ward	– auto-identification; auto trigger-related necessary processes
P8: Automatically associate equipment to ward in the RFID-enabled-Mobile asset tracking system	– auto-identification; support decision-making; help planning
- Restocking	
P9: Automatically read the RFID tag at exit of ward as equipment leaves the ward	– auto-identification; auto trigger-related necessary processes
P10: Automatically register the exit of equipment and disassociate it from the medical unit in the RFID-enabled-Mobile asset tracking system	– auto-identification; auto trigger-related necessary processes
P11: Automatically read the RFID tag when the equipment enters the storage room	– auto-identification; auto trigger-related necessary processes
P12: Automatically register the entrance of equipment in the RFID-enabled-Mobile asset tracking system	– auto-identification; auto trigger-related necessary processes
P13: Automatically read RFID tag as equipment is placed on shelf at storage location	– auto-identification; auto trigger-related necessary processes

Table 6-1 Emergent intelligent processes (Ps) with the RFID mobile asset tracking system (Cont.'d and end)

Usage activities	
- Start-of-usage of equipment	
P14: Once the push button is pressed, automatically update the RFID-enabled-Mobile asset tracking system to indicate that equipment is being used; hence, equipment is accounted as "in use"	– auto-identification; auto status change; support decision-making; help planning
- Patient care P15: Automatically match patient, clinical staff and equipment (given that patients and staff are provided with RFID-enabled wristbands and RFID-enabled badges respectively)	– auto-identification; auto-verification; support decision-making;
P16: Automatically disassociate patient, clinical staff and equipment (given that patients and staff are provided with RFID-enabled wristbands and RFID-enabled badges respectively)	– auto-identification; support decision-making
- End-of-usage of equipment	
P17: Once the push button is pressed, automatically update RFID-enabled-Mobile asset tracking system when equipment is no longer in use and account equipment as "available"	– auto-identification; auto status change; support decision-making; help planning
P18: Automatically send an alert to the storage room personnel when equipment is no longer in use, and ready to be restocked	– auto-identification; support decision-making; help planning
-Transfer between wards *	
P19: Automatically read the RFID tag at exit of ward as equipment leaves the ward	– auto-identification; auto trigger related necessary processes
P20: Automatically register the exit of equipment and disassociate it from medical unit in the RFID-enabled-Mobile asset tracking system	– auto-identification; auto trigger related necessary processes
P21: Automatically read the RFID tag at entrance of ward	– auto-identification; auto trigger related necessary processes
P22: Automatically associate equipment to ward in the RFID-enabled-Mobile asset tracking system**	– auto-identification; support decision-making; help planning
Maintenance activities	
P23: Automatically send alerts to maintenance personnel when equipment that is either due for preventive/ scheduled/ maintenance, or due for repair (corrective maintenance) or recalled moves through RFID-enabled zones	– auto-identification; auto-verification; support decision-making; help planning
P24: Automatically locate equipment that is due for preventive/scheduled/corrective maintenance or needs to be recalled.	– auto-identification; support decision-making; help planning
P25: Automatically read RFID tag as equipment enters technical department	– auto-identification; auto trigger-related necessary processes
P26: Automatically associate equipment to technical department in the RFID-enabled-Mobile asset tracking system	– auto-identification; support decision-making; help planning
P27: Automatically change status of equipment on the RFID-enabled-Mobile asset tracking system from available to under maintenance	– auto-identification; auto status change; support decision-making; help planning
P28: Automatically read RFID tag when equipment leaves the technical department	– auto-identification; auto trigger-related necessary processes
P29: Automatically register the exit of equipment in the RFID-enabled-Mobile asset tracking system	– auto-identification; auto trigger-related necessary processes

** Instead of being restocked after end-of-usage, some pumps will be taken or transferred to other wards in order to treat other patients.*

***Process regarding start-of-usage, patient care and end-of-usage (P14-P18) will follow once equipment enters new ward.*

6.4.3 Addressing past inefficiencies with the RFID system

The 29 RFID-enabled processes presented in Table 6-1 have the potential to solve the main problem raised by the participants, namely the lack of asset visibility. These processes address the six inefficiencies previously identified in Figure 6-4.

Table 6-2 Addressing past inefficiencies with emergent intelligent RFID-enabled processes

Past inefficiencies	*Emergent intelligent RFID-enabled processes*
Rank 1: Inventory shortages	• P1- P14, P17, P18, P19-P22, P25-P29
Rank 2: Asset sub-utilisation	• P1, P8, P10-P14, P17, P18, P20, P22
Rank 3: Waste of staff time	• P1, P3, P5, P12, P14, P18, P23, P24, P27
Rank 4: Service delays	• P1, P17, P18
Rank 5: Maintenance delays	• P6, P23-P29
Rank 6: Information 'silos'	• P1, P15, P16

From inventory shortages (rank 1) to improved inventory management

Picking- and distribution-related activities are automated. Instantaneous equipment check-out as equipment leaves the storage room eliminates errors related to inventory counting and allocation. Automatic equipment status change functionalities, regarding availability of equipment, fosters better inventory management practices and reduction of equipment shrinkage. When the status of equipment changes to available (equipment no longer in use), clerks are automatically alerted so that restocking activities could be undertaken and that equipment could be allocated to another patient.

A capability that was contemplated but discarded for the pilot project involved alerts triggers, which could be programmed into the system to inform staff when equipment leaves the hospital, preventing unauthorized removal of equipment and theft. Smart shelves in the storage room could facilitate inventory management and foster improvement regarding asset shortage occurrences. Assets placed in the storage room smart shelves are accounted as available inventory, and as they are taken from smart shelves (P2, P3), their location is updated, and the system reports equipment removal from the shelves. The system has the capability to automatically update shelf inventory levels in the warehouse management system (WMS), and perform an automatic verification; hence, alert if inventory levels are under requirements or near zero. However, as the RFID solution agreed upon by project participants targeted only the identification, location, and tracking of assets, this functionality was discarded.

From asset sub-utilisation (rank 2) to a more optimal asset utilization

Automatic tracking of equipment whereabouts permits to have a detailed vision of equipment usability rates; allowing informed decision-making to avoid sub-utilization of assets. Automatic equipment status change functionalities (P14, P17, P27) offer information on the exact time equipment has been in use, permitting to plan equipment allocation targeting optimal utilization rates. RFID offer opportunities to better distribute equipment to meet clinical demands; thus enhancing equipment allocation and utilization rates.

From waste of staff time (rank 3) to increased productivity

The RFID system eliminates unnecessary manual searches and movement of staff. Visibility on the location of each uniquely identified asset (P1) offers the opportunity for clinical and non-clinical personnel to look in a timely manner for the equipment that is most efficiently located (e.g. closest to the point-of-usage; closest to personnel's current location, etc.), thus saving staff time. Equipment automatic status change functionalities (e.g. in use, not in use, in maintenance) permits to have an overall picture of which assets are available and which are not; permitting staff to only go look for needed available ones and reducing unnecessary manual searches. Further, automatic equipment checkouts at the storage room permit a more efficient use of clerks' time (P3, P5). Non-added value activities, such as reading barcodes attached to equipment and registering manually or semi-manually the exit of equipment in the designated information system, are no longer needed. As well, real-time information on the location of equipment that is ready to be restocked expedites clerks' restocking activities (P18). On the other hand, smart shelves also allow staff timesaving since it permits to rapidly find the exact location of equipment on one specific shelf. This is an interesting application when a lot of different equipment needs to be managed at one storage location.

From service delays (rank 4) to timely patient care services

Timely and accurate location of needed assets (P1) eliminates long waits to get needed equipment, thus accelerating patient care delivery. Key capabilities offering timely information on asset location and availability could assist the staff decision-making process regarding equipment allocation and help them to better plan care delivery. Moreover, thanks to this new level of asset visibility, storage room clerks are able to follow the equipment as it rotates throughout the hospital RFID-enabled zone (the 3 units that were part of the pilot); hence, they have near real-time information on the exact location of their RFID-enabled assets circulating in this zone (P5, P8, P10, P12, P20, P22).

Better visibility of assets could permit performing maintenance activities in an opportune manner, since equipment can be found (P23, P24), expediting maintenance activities; thus positively influencing the total available equipment inventory to support patient care.

From maintenance delays (rank 5) to better maintenance compliance

Automated notifications (P23) could have been set up into the system so that maintenance personnel is advised when equipment due for maintenance (preventive, scheduled, etc.) enters an RFID-enabled zone (e.g. storage room or medical ward) so that they can retrieve it, avoiding delays of maintenance activities and allowing compliance with maintenance programs. In case of recalls from the manufacturers, automated alerts (P23) could have been set up as well in order to notify biomedical technicians once recalled equipment enters an RFID-enabled zone (e.g. storage room or medical ward). Automatic location of assets (P24) that need service from the maintenance department allows for the improvement of the response from maintenance personnel and expedites maintenance activities.

From information 'silos' (rank 6) to increased information visibility and sharing

The RFID-enabled mobile asset tracking system offers real-time information to a wide range of professionals at the same time (P1-P29), so that all interested parties could have access to asset-related information, facilitating decision-making and planning. Seamless information sharing is possible with the RFID system in place; indeed, information about tracking and tracing of equipment registered at one specific unit or department in the hospital (P3, P5, P8, P10, P12, P20, P22, P26, P29) could be available to all interested parties who are not necessarily staff of such a unit or department.

6.5 Conclusion

Mobile medical devices in general and digital IV pumps in particular represent essential resources to support a wide spectrum of patient care activities in hospitals. Empirical evidence points to the lack of visibility of these devices as the major stumbling block for a more appropriate asset management. The lack of visibility into the real-time location and status of digital IV pumps generates six interrelated inefficiencies, namely, and, in order of their relative importance, inventory shortages, asset sub-utilization, waste of staff time, service delays, maintenance delays and information 'silos'.

The potential of RFID to trace and track moving medical equipment was tested as a proof of concept in a phased roll-out implementation limited to three hospital units, restricted to one type of asset- i.e. digital infusion pumps, and conducted with existing legacy systems. Results from the proof of concept proved that the RFID system allows real-time tracking and tracing of uniquely identified IV pumps, and supports the clinical and non-clinical staff in their daily activities. Moreover, it offers some characteristics related to ambient intelligence: it is context aware, it is transparent with no perceivable interfaces (except for the push button) and it communicates with its environment. Adding some level of intelligence to mobile asset management processes is undoubtedly the most important benefit that could be derived from the RFID system. Results show that the added intelligence can be rather basic (auto-status change) or a bit more advanced (personalized automatic triggers). More importantly, adding intelligence improves planning and decision-making processes. Finally, the RFID system solves the problem of the lack of visibility for IV pumps and reduces the above-mentioned inefficiencies.

The phased roll-out implementation of the RFID system allows the gaining of knowledge and experience, and demonstrates that the emergence of "intelligent" processes associated to warehousing, usage, and maintenance activities of IV pumps improves mobile asset management while keeping the focus on patient care at the same time. A full roll-out implementation for different types of mobile assets in all units in the hospital should be the next logical step. Although the RFID system was a technological success, the full roll-out implementation may be challenging in the specific context of hospitals. First, the financial aspect cannot be overlooked: hospitals face strict financial constraints and the return on investment of a full implementation has to take into account one major intangible, namely the quality of health care. If "health care quality measurement is at least 250 years old" [76, p.i5], its monetary value is still difficult to estimate. Second, the very characteristics of hospitals, qualified as complex professional bureaucracies, constitute a unique set of constraints for a full roll-out implementation. In particular, organizational inertia, complexity and inflexibility are not conductive to hospital-wide changes. As long as RFID integration was limited to three receptive units within the hospital, the implementation went rather smoothly despite some noticeable divergences between the clinical and non-clinical staff. A full roll-out implementation entails a redesign of processes throughout the entire hospital, though changes to daily activities appear to be minor. Nurses will need to press push buttons to inform the system of the use or non-use of mobile equipment, clerks will need to rely on a new system to retrieve information about equipment, biomedical technicians will need to access the tracking application to locate portable equipment that must be maintained, and IT personnel will need to maintain and troubleshoot the new RFID system.

From the above discussion, the phased roll-out implementation which was carried out during this study proved the acceptability of RFID in the specific context of mobile asset management. Such acceptability even entails the emergence of intelligent processes. But, the results presented in this paper strongly suggest that acceptability does not mean acceptance and appropriation, especially in hospitals. In fact, the potential of the retained RFID system for a full roll-out implementation was qualified as "*diluted*" by some participants. To others, several processes, in particular those related to maintenance, were "*shoved down*": the maintenance status and tracking capabilities were discarded, although most agree that the probabilities of errors or missteps could also decrease if processes related to maintenance activities would have been retained. Inventory updates represented a functionality definitively targeted by the hospital administrators; however, given that such a capability demands interoperability with existing enterprise applications (for instance, with WMS), it was not deployed to avoid complexity. The concepts of acceptance, acceptability, and appropriation in professional bureaucracies such as hospitals need to be further investigated in order to better understand the drivers of the adoption, implementation and diffusion of ICTs in general and of RFID in particular.

6.6 References

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CHAPITRE 7 GENERAL DISCUSSION

This last chapter offers a discussion of the overall results presented in the three thesis articles (section 7.1). In particular, it assesses the level of support for the research propositions (7.1.1) and revisits the concepts of acceptance, acceptability and appropriation (section 7.1.2). Research limitations are discussed in section 7.2 while contributions examined in section 7.3.

7.1 Overall results and discussion

7.1.1 Results related to the research questions

Within the context of one hospital and with respect to one specific RFID application, namely an RFID-enabled mobile asset management application, the thesis seeks to find answers to three key research questions: Why RFID is implemented? How RFID implementation is carried out? So what? or Does RFID really improve mobile assets management? Answers to these three questions were investigated in the light of the empirical data collected over a 25 month period. Some answers to these three questions are found in the thesis articles (referred hereafter as A1, A3, and A3). The following paragraphs offer more detailed explanations.

To the question **why RFID is implemented?** The most straightforward answer is given in the third thesis article: “RFID could reduce the existing inefficiencies related to mobile assets management, in particular those related to the management of infusion pumps” (A3, conclusion, p. 140). Article 2 points also to the current inefficiencies with respect to medical assets management and tracking as the main motivation behind RFID adoption. Technological preparedness and readiness drive RFID implementation. This includes familiarity with IT innovations within the hospital (A1) and compatible existing infrastructure (the hospital is almost 100% Wi-Fi enabled) (A1). It is important to notice that, depending, on the targeted application, a minimal level of IT infrastructure is required. For this particular implementation, it was mandatory to have WiFi in the areas where RFID was deployed. Results also demonstrate that technological preparedness and readiness also build on the experience of technological partners with RFID implementation in various sectors (A2). Finally, results indicate that the implications of key players (A1), the presence of a project champion (A2), the knowledge of the organizational context where the implementation takes place (A2), the strategic alliances among technological and non-technological partners (A2), and end-users training (A2) play a significant and positive role in the RFID implementation.

Our results confirm that some factors hamper RFID implementation (Samno et al., 2012; Xinrong, 2010; Kumar et al., 2010; Lin and Ho, 2009; Kumar et al., 2009; Roh et al., 2009; Lin and Ho, 2009; Castro and Fosso Wamba, 2007;), such as the high cost of RFID infrastructure (A2, A3), substantial process redesign (A3), several technical difficulties such as weak Wi-Fi coverage in some specific areas in the hospital (A3), some resistance from the medical staff to go beyond the tracing and tracking capabilities of RFID (A2), and the very characteristics (Mintzberg, 1989; Håland, 2012) of hospitals as complex professional bureaucracies (A3).

How RFID implementation is carried out? Article 2 provides most answers as it examines prevailing issues for each stage of the implementation model and the corresponding decisions made at such implementation stages. This proved to be beneficial to reach an agreement to advance across the implementation stages. Some prevailing issues dealt with technology related matters and technological decisions were punctual, precise and consensual. The continuous improvement of care services was without a doubt the superseding concern expressed by all participants from the Dutch hospital. However, expectations and requirements differ among different groups of participants and decisions made in a previous implementation stage were questioned and re-assessed. This second article demonstrates that "the most significant issues are not technological but are mainly organizational, as they seem to arise from the presence of diverging perspectives". The empirical evidence presented in this paper demonstrates a cleavage between the administrative and clinical perspectives but also within the clinical perspective. However, divergences also run deep within each perspective (for instance, nurses vs. doctors) and between the technologists in the hospital (ICT managers, biomedical engineers, and maintenance specialists) and the administrators" (A2, p. 130).

Furthermore, we proposed in article 2 a five-stage implementation model (Figure 7-1) that builds on the one initially selected in chapter 3 (Ngai et al., 2010). In the proposed implementation model, we combine the “Project feasibility and scoping” and the “Project team formation” stages into one stage that we identified as “ Pre-feasibility” since key aspects related to the scope and particularities of the project need to be raised and addressed by the dedicated project team before investing in a feasibility study. The new proposed model removes one stage from Ngai and co-authors’ model, namely “Hardware adaptation to environment” because hardware is only one part of the RFID infrastructure that need to be deployed; thus, it is included in stage 3 (Figure 7-1) that we called “RFID scenario building and validation”. We have also renamed the Ngai and co-authors’ last stage (“Continuous improvements”) and proposed “Post-implementation- benefits assessment” because of the overwhelming importance to pinpoint these benefits given the high level of uncertainty implicit in RFID implementation projects, in particular an uncertain ROI, an emergent and disruptive technology, and potentially wide-ranging organizational changes regarding work practices. Ngai and co-authors did not focus on benefits assessment specifically in the continuous improvement stage, but they mentioned the following: “Once the RFID system is implemented and used by users, the metrics collected from the implementation must be reviewed by the project management.” Let us note here that we have attempted to offer an indication of those metrics, that we called KPIs in article 2 and proposed a KPI framework (A2, p. 128).

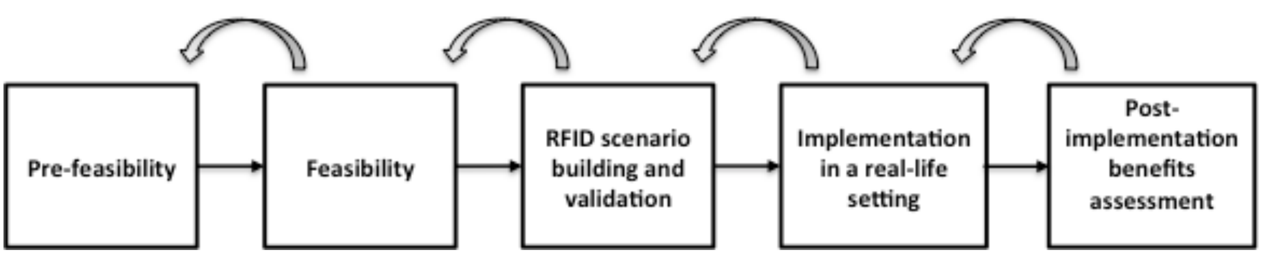

Figure 7-1 Proposed RFID implementation model

Although implementation models are usually displayed in a linear fashion, article 2 demonstrates that the process of RFID implementation is highly iterative as "participants revisited and modified previously agreed steps" (A2, p. 130).

To the question So what? - i.e. Does RFID really improve mobile assets management?-. Articles 1, 2 and 3 provide ample empirical evidence to answer this third research question. Our results suggest that benefits identified and evaluated during the real life RFID implementation belong the following broad categories: improving assets visibility, promoting operational efficiency, reducing costs and facilitating the emergence of intelligent processes.

- The improved visibility of infusion pumps (A1) is given by the real-time access to information about the location, the movement and the status (in use, not in use; in maintenance, not in maintenance) of any RFID-enabled pumps (A2). Such information can be easily accessible and shared (A3). In short, RFID allows the real-time tracking and tracing of uniquely identified infusion pumps (A3). This is in line with the literature. Previous supports widely that RFID has the potential to improve visibility, by improving tracking and tracing (Park et al., 2010; Roh et al., 2009; Mehrjerdi, 2011; Bendavid and Cassivi, 2012)
- The literature suggests that RFID has the potential to enhance operational efficiency (Ngai et al., 2012; Mehrjerdi, 2011; and Park et al.2010). Our empirical results specify that the increased operational efficiency arises mainly from the elimination of non-value added activities (A1), leading optimal asset utilization (A3), increased productivity (A3), timely patient care services (A3), tighter inventory management (A3) and better maintenance compliance (A3).
- Costs related to the management of infusion pumps are reduced because staff is able to get their hands on infusion pumps when and where needed (A1), without spending valuable time searching for these devices (A1, A2, A3). This results in labor costs savings but it also enhances the quality of service delivery to patients and improves the level of processes control desired by medical professionals (A3). Inventory shrinkages

and unnecessary purchases and rentals of mobile medical equipment are avoided, bringing cost-saving opportunities (A3). These later benefits were particularly the interest of top management and biomedical managers.

- The emergence of intelligent processes was mainly explored in article 3. Intelligent processes are mainly derived from the RFID capabilities for auto-identification and context-awareness (A3), process automatic status change (A3), and, automatic update in hospital's enterprise applications (i.e. WMS) (A3). Article 3 further demonstrates that intelligent processes improve planning and decision-making. We believe that the emergence of intelligent processes represents the most critical area of benefits that can be derived from an RFID implementation.

Some benefits derived from RFID may be difficult to pin down. This is the case when we state that RFID allows the introduction of *new practices.* For instance, the supply of infusion pumps that was previously centralized under the responsibility of the staff in the storage room becomes decentralized with RFID: Nurses and other staff members can locate by themselves the equipment with the Enterprise Tracking Software. Further, equipment managers can use historical data collected via the RFID-based asset tracking system to better forecast and plan equipment allocation across sites, to better assess when maintenance is required or to better redistribute equipment within the hospital. The latter could open new opportunities such as a more adequate and timely response to critical and unexpected clinical demands (for instance, emergency care where each minute is critical for delivering patient care). The added intelligence brought by RFID also allows foreseeing *new avenues for ambient intelligence*, as RFID-enabled objects (here infusion pumps) become context aware.

Other benefits are easier to trace by relying on KPIs (Key performance indicators). Article 2 proposes a first list of KPIs for specific activities (receiving, put away, picking, distribution, restocking, and usage) directly related to mobile assets management. These KPIs could be used to evaluate the benefits derived from RFID during the post-implementation stage.

7.1.2 Support for the research propositions

In the following paragraphs, we will discuss the level of support obtained for each of the research propositions presented in chapter 3.

Proposition 1*: The organizational context (hospitals as professional bureaucracies) and type of RFID application (mobile assets management) have an influence on the factors driving or hampering RFID implementation, on the impacts and benefits resulting from implementing RFID and on the future RFID implementation (relationships explored by P2, P3, and P4).*

Level of support: *Strong support for the organizational context, partial support for the type of RFID application.*

Organizational context: The very characteristics of hospitals, qualified as complex professional bureaucracies, constitute a unique set of constraints to be taken into account for RFID implementation. In particular, organizational inertia, complexity and inflexibility are not conductive to hospital-wide changes (A3) and affect how RFID is implemented. Moreover, the existence of a dual power structure and a tendency to culture entrapment may have a profound impact on the importance of the benefits derived from RFID. In particular, the different perspectives we identified in articles 2 and 3 appear to denote the presence “irreconcilable mind-sets” - an expression first introduced by Mintzberg and Glouberman in 2001- that hampers the pursuit of common benefits. For example, the perspectives from the non-clinical staff and clinical staff introduce large distortions when assessing the importance given to maintenance activities and smaller ones when evaluating the importance of reducing infusion pumps inventory shortages.

Type of RFID application: The three thesis articles focus on mobile asset management for one category of assets, namely infusion pumps. Scalable implementation (A1 and A2) could be extended to other mobiles assets such as feeding pumps, wheelchairs, ventilators, pulse oximeters, etc. Full roll-out would involve tagging of all assets, at all wards, at all services across the hospital. One could expect similar results for a wider RFID application in a full roll-out implementation but this cannot be demonstrated from our results.

Propositions 2 and 3

As propositions 2 and 3 are respectively linked to two research questions, namely Why RFID is implemented? Does RFID really improve mobile assets management? The level of support obtained from the thesis articles for these two propositions has already been addressed in the previous pages (section 7.1.1) will summarize the support as follows:

Proposition 2: Some factors are highly influential. Hence, they are driving or hampering the decision to implement RFID and the implementation process.

Level of support: *Strong support.*

Proposition 3: *RFID implementation generates different impacts and benefits (perceived or real).*

Level of support: *Strong support, in fact the strongest support compared to other propositions*

Proposition 4

Some RFID benefits were expected by most participants in stages 1 and 3 of the implementation model (Figure 7-1). Once RFID was implemented, several benefits became real as support for proposition 3 demonstrates. Do these real benefits influence <u>future</u> RFID implementation? They do to some extent, but their influence is mitigated by diverging perspectives. The relative importance of these benefits varies between clinical vs. non clinical, within the clinical side (disagreements between nurses and physicians) (A2) and within the non-clinical side (disagreements between storage room staff and biomedical department staff) (A2). These diverging perspectives hamper future RFID implementation.

Proposition 4: *The impacts and benefits derived from RFID implementation modify the relative importance of factors driving or hampering future RFID implementation.*

Level of support: *Very partial support.*

Proposition 5

The fifth proposition implies that the relationships explored by P2, P3, and P4 were first thoroughly examined and this was expected from the start of our research. What was not anticipated is that we only gained a deeper understanding of acceptance, acceptability and appropriation of RFID at an organizational level at the post-implementation stage of the implementation. This improved understanding is partially reflected in article 3, but has to be addressed in more details in the thesis. The next section (section 7.1.3) thus provides additional support to proposition 5.

Proposition 5: *The level of RFID acceptance, acceptability and appropriation has an influence on the relationships explored by P2, P3, and P4.*

Level of support: *Very partial support.*

The overall support for all research propositions is displayed in Figure 7-2

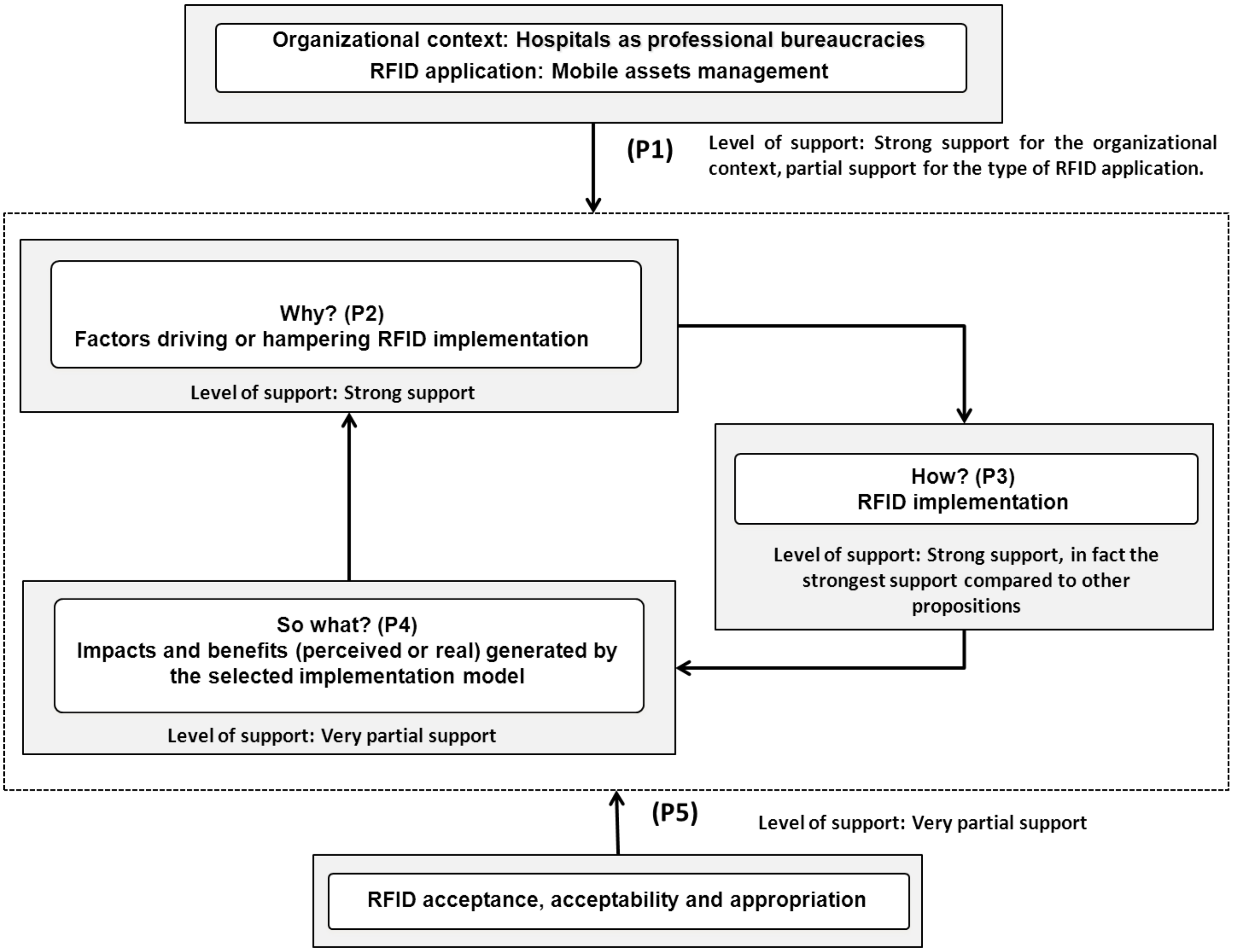

Figure 7-2 Level of support for the five research propositions

7.1.3 Additional support for the concepts of technology acceptance, acceptability, and appropriation

Technology acceptance

In chapter 2, we have proposed that technology acceptance refers to *the demonstrable willingness of an individual, a user group, or an organization to use the technology* (chapter 2, p. 32). Was RFID accepted? From our empirical data, RFID acceptation seems to vary depending on the implementation stage and, within one implementation stage, according to the level of analysis (individuals, groups or an organization). At the individual level, participants believed in the use of RFID from the very beginning, namely at the pre-feasibility stage, although most of them admitted that they did not fully understand the technology itself nor its potential. At the group level, RFID acceptance varies through all implementation stages according to their core expertise and their hierarchical status. In fact, the ICT group which is part of the *technostructure* of the hospital demonstrated the highest willingness to implement RFID while the personnel at the front line or *the operating core*, especially nurses, wondered if the use of RFID will require new tasks. The top management of the hospital has adopted a wait and see attitude in the first implementation stages until the implementation in real life proved some benefits but they insisted on the hospital preparedness and readiness as organizational antecedents of RFID use. They see their hospital as modern, technologically advanced and mostly wireless: these characteristics strongly suggest technological preparedness and readiness are antecedents of RFID acceptance. We agree here that technological readiness and preparedness play a significant role in the RFID organizational acceptance process as noted by Richey and Autry (2010) but we believe that they are far from being the only not factors leading to acceptance. Indeed, organizational acceptance of RFID depends more strongly on the behavioral and social acceptance of different groups within the hospital that display distinctive occupational cultures. The cleavage between these groups goes far beyond the clinical vs. non-clinical perspectives as stated in article 2. Empirical data demonstrate that RFID acceptance is a multi-level, multi-facetted and complex phenomenon.

Technology acceptability

From the literature review, we have simply defined technology acceptability as *the extent to which a technology is accepted by an individual, a user group or an organization* (chapter 2, p. 32). The three thesis articles proved that practical acceptability of RFID throughout the five stages was fairly high and agreed upon by all participants: the RFID scenario was compatible with the existing infrastructure, was useful to remove the main agreed upon inefficiencies related to the management of infusion pumps, was reliable, and, even entailed intelligent processes.

However, costs were raised as an issue (A2) and thus lower the practical acceptability of the RFID-enabled mobile assets management application. Social acceptability is shaped by norms, constraints or attitudes. Since tagging patients and hospital staff was discarded at the prefeasibility stage, social acceptability, without the privacy issues, was high: after all, healthcare services will improve, frustrating inefficiencies such as lengthily searches for available infusion pumps by clinical professionals and non-clinical staff or recurrent shortages of inventory in the storage room will disappear, and, operating costs will be reduced (A2 and A3). It is interesting to notice the social acceptability remained high throughout the five implementation stages, but its focus shifted from a multi departmental and multidisciplinary approach to a narrower one based strictly on the core mission of the hospital, i.e. patients care. In fact, intelligent processes pertaining to maintenance activities such as repair, recall, and recycling of medical devices were discarded as a first priority in stage 3. What was collectively acceptable in earlier stages of RFID implementation was no longer acceptable in later stages. The focus (but not necessarily the level) of social acceptability within the same organizational context changes as time passes by and as everyone goes back to their usual daily tasks.

Technology appropriation

We defined previously appropriation as *a process of social construction that allows individuals, user groups or an organization to make the technology their own* (chapter 2, p. 32). Appropriation thus entails an explicit RFID scenario that fits the specific needs of the hospital. These needs were collectively identified, assessed and evaluated by participants in the focus groups (A2). It also entails that RFID will be used, once implemented in real life, to serve additional needs that were not originally expressed. The rationale being that the technology, here RFID, empowers the users but our empirical results did not prove this last statement. On the contrary, the users seem to disengage themselves from the technology at stages 4 and 5. The expressions from the ICT group to describe such disengagement were: we end up with a "washed down" version of a successful RFID application or this is now a "diluted" and "less interesting" RFID implementation.

Figure 7-3 summarizes the above discussion in terms of our findings for RFID acceptance, acceptability and appropriation at the organizational level. This figure was derived from the content analysis of the qualitative data gathered from field observations, interviews, focus groups and panel discussions. A similar analysis could have been conducted at the group level (comparing different perspectives) or even at the individual level. Figure 7-3 reflects the statement we made in the conclusion of the third article for the post-implementation stage: "Results presented in this paper strongly suggest that acceptability does not mean acceptance and appropriation, especially in hospitals" (p. 166).

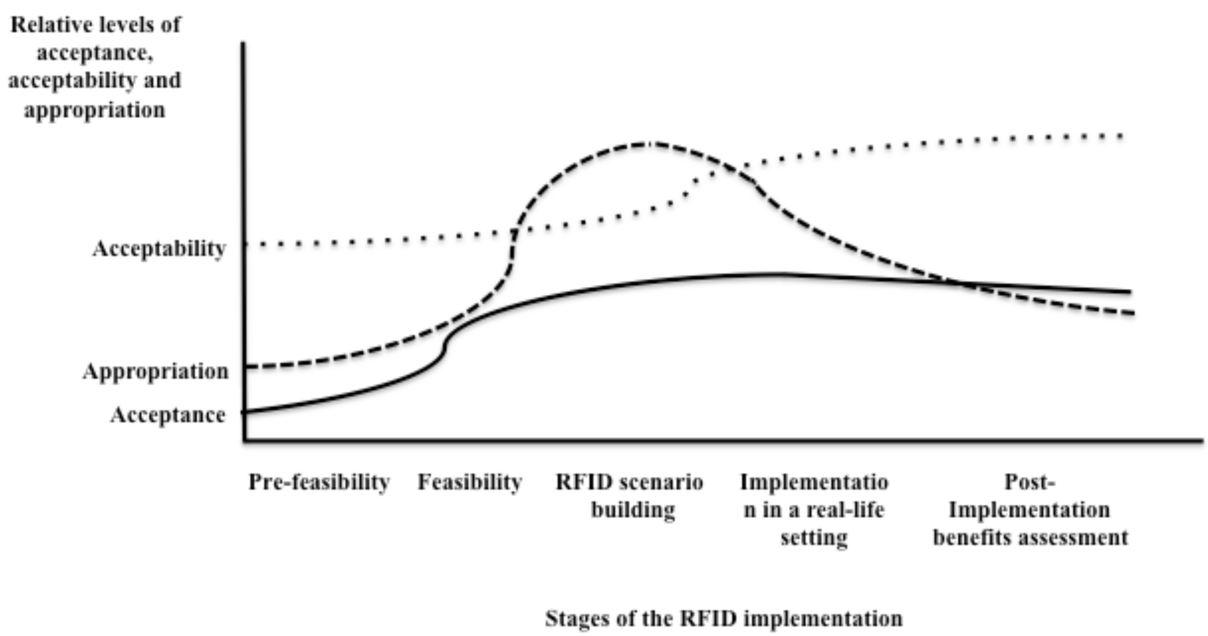

Figure 7-3 RFID acceptability, acceptance and appropriation at the organizational level

Two main observations arise from the empirical data. First, it could be stated that if technology is accepted, acceptable and appropriated, then it is fully used. By extension, acceptance, acceptability and appropriation could be significant not only in explaining the extent of use of a technology (partial use vs. full use), but also the reasons why a technology was initially adopted and then discarded. Second, empirical results reject the presence of a chronological order between the three concepts. For instance, appropriation does not follow acceptance, even initially. Rather, acceptance, acceptability and appropriation coexist at any time during the implementation process and the dynamic interplay between the three concepts needs to be further investigated. However, chronology still matters as Figure 7.2 suggests that the levels of acceptance, acceptability and appropriation should be closely monitored over time. We would also add that these three concepts are sensitive to both the technology (in this case RFID) and to the context where it is used (the hospital), which are also changing over time.

7.2 Limitations

The statement that “all research work unavoidably has some limitations” (Ioannidis, 2007, p. 324), holds true, especially when research is based on empirical evidence. However, Ioannidis makes compelling arguments for disclosing more thoroughly research limitations as they are “not properly acknowledged in the scientific literature”. This section will therefore examine as closely as possible the inherent limitations of this research and will anchor the discussion around two sets of shortcomings: 1) limitations resulting from the proposed conceptual framework and 2) limitations arising from the research design.

7.2.1 Limitations linked to the conceptual framework

We acknowledge that the proposed conceptual framework was too ambitious. Answering the three research questions (especially the how?) throughout a real life RFID implementation might have been a more reasonable undertaking. However, the initial intent of this thesis that emerged from field observations can be stated as follows: Information technologies, once they are adopted and implemented, are not necessarily fully used. This is even more evident in professional bureaucracies such as hospitals and with potentially disruptive such as RFID. The concepts of acceptance, acceptability and appropriation may provide valuable insights into the investigation required by our initial intent. These concepts entail several problems: first, they are complex and ill-defined (chapter 2); second, they evolve in a dynamic interplay, and, third they are influenced by the use context and the technology, the latter also changing over time. The first problem can be grasped from the start with the literature review. The second and third problems were uncovered after the conceptual framework was proposed and during the data collection period.

The proposed conceptual framework and its corresponding research propositions could have been modified in order to remove the concepts of acceptance, acceptability and appropriation (such process resembles to reverse engineering).

From the above discussion, we have to recognize that proposition 5 could not be explored in the level of detail we have initially anticipated and received a very partial support from the empirical evidence we collected. On the theoretical front, this is a drawback that could be addressed in future research work. As our research was designed through an inductive stance, this seems appropriate. On the research diffusion front, it is a major obstacle to overcome as publication is biased towards positive results (Song et al., 2010) although one can argue that negative results or no result are still results.

7.2.2 Limitations linked to the research design

As stated in chapter 3, the research design represents an exploratory initiative based on action research and conducted in a longitudinal single fieldwork case study. Such design generates several limitations.

The choice of a single case raises the question of external validity since the generalization of the results and extrapolation of findings to other hospitals is problematic. A multiple case study will increase to some extent the external validity (Yin, 2009) while the positivistic inquiries with a large number of respondents display the highest level of external validity. However, the internal validity of a single case study is much stronger as issues, subtleties or dynamics could be assessed in more depth. Striking the balance between external validity and internal validity depends on the nature of the research. As exploratory research favors internal validity, the single case study seems appropriate.

The choice of a Dutch hospital as the primary observation site as well as the selection of eight participating organizations may raise some concerns. This was a multinational initiative with organizations from four countries (Netherlands, Canada, United Kingdom and USA). Could cultural differences introduce some biases? Language was not a barrier as all oral and written communications were made in English and some internal documents in Dutch were translated. The lack of formality on the Dutch side was surprising: for instance, the hospital director met regularly with and was available to all participants. The two Ph.D. candidates could easily meet him. We do not believe that cultural differences, included lack of formality, affected the results but it influenced positively the data collection process. Since the Dutch hospital is the primary observation site where RFID was implemented, are findings transferable to other European or Canadian hospitals? To a large extent, the answer is positive. But, even if the hospital administration was cost conscious, costs were not the overriding factor in the decision to implement RFID and in the evaluation of benefits. Costs constraints exist, but do not seem as severe as in American or Canadian hospitals. Transferability of some findings to North-American hospitals has to be closely assessed.

Action research brings its own set of limitations. First, as researchers were actively involved in the RFID implementation process, they have to maintain their own objectivity throughout the ups and downs of the implementation process. One significant issue concerned the intellectual property for the two Ph.D. students: the directors from the university-based centers (one Canadian, one Dutch) set their respective disciplinary field, their own line of inquiry and their own data collection technique (for instance, facility management and internal logistics supported with RFID for the Dutch Ph.D. student; technology and innovation management, and RFID for the Canadian Ph.D. student). Mere specifically, the role of the Canadian Ph.D. student consists of the following: 1) active participation of all phases of the data collection, from the planning, the scheduling, the gathering, the recording and the iterative validations; sole responsibility for data recording documents and process mapping; 2) direct implication in the development, selection and validation of the technological scenario, including her suggestions for specific RFID tags; and 3) main responsibility for data analysis, presentation and interpretation. The determining role of the Canadian Ph.D. student may raise issues regarding potential problems dealing with subjectivity of the research. We therefore try to lower such problems by structuring and formalizing the data (for instance, with process mapping), by repetitively checking the accuracy of the empirical data with semi-structured interviews, focus groups and panel groups and by relying on past experience from the two co-directors and their continuous supervision. The second significant issue raised by action research deals with ensuring anonymity and confidentiality. This goes beyond the simple fact of erasing the names of the participants. For instance, we cannot give specific technical details about the RFID infrastructure (the type of RFID tags, the decision rules for the middleware, etc.) without indirectly disclosing the participating organizations. The practical value of some of our findings is therefore lowered.

Reliability may represent another limitation mainly raised here by the use of qualitative data. We therefore attempted to increase reliability by structuring all data recordings in a systematic and consistent way (as it was illustrated in the research journal in chapter 3, for instance). This is in line with the principles initially proposed by Schatzman and Strauss in regards to data recording as they argue that data recording contains "as little interpretation as possible and are as reliable as the observer can construct them" Schatzman and Strauss (1973, p. 110). Furthermore, the process mapping establishes the structure and necessary rigor for interpreting and validating the field observations made by the researchers.

The research design required a longitudinal field study that covered RFID implementation for 25 months, from the prefeasibility (stage 1) to post-implementation benefits assessment (stage 5). Stage 5 was partially investigated for 11 months because of time and resources constraints. This introduces a positive bias towards the first four implementation stages and prevents an in-depth exploration of under investigated issues related to post-implementation. A longitudinal study also introduces the risk of being flowed by enormous volumes of empirical data, making the data analyses very laborious and time consuming. This shortcoming may lead to data saturation.

7.3 Contributions

Contributions are here assessed from the methodological perspective (section 7.4.1), the theoretical perspective (section 7.4.2) and the practical perspective (section 7.4.3).

7.3.1 Methodological contributions

Since internal validity represents a key characteristic of our research design, special attention was placed on triangulation. Data triangulation (Yin, 2009) was attained by relying on different data sources and by collecting the same data in different points in time during the RFID implementation. The fact that several researchers participated in the data collection, data analyses and interpretation leads to an additional and complementary form of triangulation. Finally, different data collection techniques were used, allowing a third form of triangulation. Data source triangulation is usual in field research, but the last two forms, known respectively as investigator triangulation and methodological triangulation (Guion et al., 2011; Jack and Raturi, 2006), are less frequent.

Process mapping is increasingly used in field research (Bendavid and Cassivi, 2010). Our research proved that it is valuable for exploring real-life complex phenomenon: Process mapping improves the initial understanding of an observed phenomenon, facilitates structured and meticulous documentation, serves as an anchor point for the semi-structured interviews, the focus groups and the panels, permits multiple iterations and validations, and, allows the simulation of processes that integrates different RFID scenarios.

Finally, action research is especially suited for exploring the potential of new disruptive technology such as RFID in complex contexts such as hospitals. This confirms the stance taken by Waterman and coauthors “action research can be employed successfully to diffuse innovations that need a high level of adaptation in each new setting or where there is high complexity and mismatch between groups of people in an organisation, providing there is an established need for researching the said innovation further” (Waterman et al., 2007, p.380).

7.3.2 Theoretical contributions

By contrasting different theoretical perspectives, theory triangulation (Guion et al., 2011; Yin, 2009) occurs. The underlying rationale for theory triangulation is to uncover a wider range of competing or complementary theories in order to gain new and deeper conceptual insights. From the theory on the diffusion of innovations with the seminal work from Rogers to the theory of human agency, the literature offers conflicting perspectives that were presented and discussed in chapter 2. As technology implementation has to be investigated in the use context, organizational theory provides insights into the characteristics of hospitals that are typical of professional bureaucracies (chapter 1). These perspectives are not only the result of different disciplinary fields but they also fundamentally differ from an epistemological point of view. For instance, the concept of appropriation which emerges from the cognitive sciences corresponds to descriptive epistemology whereas the concept of acceptance rational choice theory stems normative epistemology. Facing the paradoxes and the ambiguities raised by these differences represents a difficult undertaking that was summarized in our conceptual framework.

Are empirical results compatible to the proposed framework? They do but the conceptual framework has to be refined or modified based in future field research and this is in line with grounded theory. However, we believe that our proposed framework may be interesting as it stresses temporality with feedback loops and iterative relationships, and thus builds on the theory of human agency (Cousins and Robey, 2005). In fact, it is based on factors arising from past capabilities and practices, considers the constraints, opportunities and contingencies stemming from the present situation and examines future implications and opportunities (Figure 7-4).

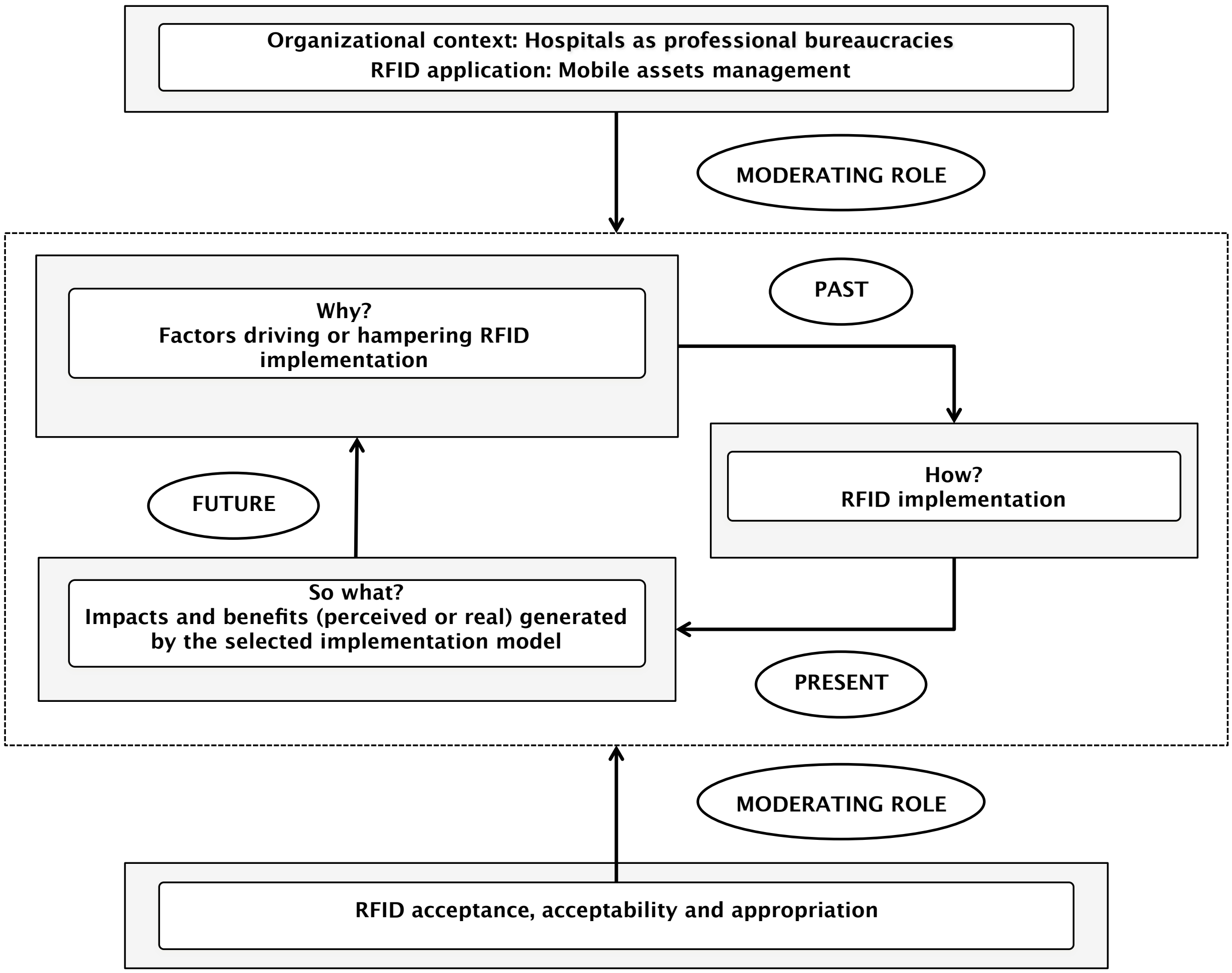

Figure 7-4 Conceptual framework: past, present and future implications and opportunities

The proposed conceptual framework may raise some additional interest as it introduces two sets of intermediary variables that may modify the relationships related to P2, P3 and P4. The first set refers to the inherent characteristics of the use context (hospitals as professional bureaucracies) and of the technology itself (RFID). The second set represents the level of technology acceptance, acceptability and appropriation. Our framework suggests that these intermediary variables play a moderating role (Figure 7.3) that could be investigated in the future.

7.3.3 Practical contributions

This research is relevant for researchers, healthcare policy makers, hospital administrators, IT specialists and IT consultants. The practical contributions from this research could be summarized as follows:

1) The concepts of acceptance, acceptability and appropriation allow a more adequate evaluation of the inherent difficulties surrounding IT implementation in hospitals and in healthcare. The implementation of EHR (electronic healthcare records) is just one example of the many IT initiatives undertaken by hospitals but that do not sustain beyond the experimentation phase (Gagnon et al., 2010). For instance, in the province of Quebec, the implementation of electronic health records was proven to be very challenging, with some observers considering this project to be a failure (Canhealth, 2011). In fact, this project is significantly over its initial budget and presents considerable implementation delays (Canadian EMR, 2011).

   Major difficulties are observed for RFID projects in Quebec's hospitals where some efforts were made to implement the technology, but very few projects have been actually carried out and few implementations have sustained. For instance, RFID have been studied in order to improve medical supplies management in hospitals in Quebec (Bendavid et al., 2012).

   A deeper understanding of appropriation is of particular interest for better designing RFID infrastructure and for offering more customized RFID applications, thus reducing some implementation difficulties.

2) A better understanding of how to implement RFID is clearly needed. Such understanding may be gained from the proposed implementation model, the discussion of the prevailing issues at each stage or from the achieved benefits. This may help practitioners with an insightful and structured method to better plan, conduct, evaluate and sustain an RFID implementation in healthcare settings.

3) Asset management performance indicators (KPIs) could be helpful to monitor the benefits of RFID during the post-implementation stage. It could be used by hospital administrators and decision makers for measuring the efficiency of mobile assets management activities, for adjusting their operations and for setting actions plans for improvement.

4) The methodological strategy offers researchers an original way to structure and record enormous quantity of data that could be otherwise overwhelming. Furthermore, “research frequently reports what practitioners say they do. In action research, the emphasis is more on what practitioners actually do” (Avison et al., 1999, p. 94). This seems particularly relevant.
5) Intelligent asset management brings some new opportunities to clinical and non-clinical practices. In fact, our research shows that the added value of RFID may lie mostly in the emergence of intelligent processes such as automatic update of inventories, automatic registry of equipment movements and transfers, automatic information on asset location, etc. Intelligent asset management may also constitute a major step for ambient intelligence in hospitals where intelligent clinical devices that communicate among each other through supporting technologies at the point-of-care.

CONCLUSION AND RECOMMENDATIONS

Our research represented a major and ambitious undertaking and offers the basis to further improve our collective understanding on RFID implementations. It is now time to identify areas for future work. Future research avenues stem from four points, namely dealing with the limitations as outlined in chapter 7, revisiting the existing empirical data from a different theoretical anchor, exploring in more depth the proposed conceptual framework and investigating future RFID applications.

Dealing with the limitations of the research design

One of the limitations discussed in chapter 7 points to the need to improve external validity. Consequently, additional investigation in RFID implementation could focus on a few hospitals in order to perform cross-case analyses and offer comparative studies. This could occur in different countries in order to uncover cultural differences, distinct implementation factors, or specific best practices related to RFID implementation. External validity could also be raised by investigating RFID implementations related to different type of mobile assets.

Post-implementation was here investigated for 11 months but this might not be long enough to grasp the complexities of RFID post-implementations. In particular, the benefits derived from RFID at the post-implementation stage should be evaluated for a longer period by, for instance, monitoring them with the KPIs presented in article 2. Furthermore, we noticed that the level of acceptability remains relatively constant throughout the five implementation stages while the levels of acceptance and appropriation drop significantly at the post-implementation (Figure 7-2). What will happen in the long term?

Revisiting the empirical data from a different theoretical anchor

The empirical data base is rich, but we did not exploit it to its full potential. For instance, our empirical data basically supports to Schon's assertion that "the new idea either finds a champion or dies" (Schon, 1963, p. 84). Since then, multiple studies have investigated the differentiated roles of champions for technological innovations (Maidique, 1980; Howell and Boies, 2004), ICTs projects (Rasmussen et al., 2011) and more specifically heath information technology (Shachak, 2012). This existing literature on the role of champions could represent a theoretical anchor to revisit our own empirical data.

Exploring in more depth the proposed conceptual framework

The proposed conceptual framework represents a starting point. For instance, the moderating roles of the use context (hospitals) and the technology (RFID) have to be examined. The concepts of acceptance, acceptability and appropriation need to be further analyzed. The robustness of the proposed conceptual framework could be tested with other ICT applications (for instance, the implementation of provincial electronic health records) or in other professional bureaucracies (for example, universities, engineering firms, and law firms).

Investigating future RFID applications

Ambient intelligence would represent one area of potential investigation which is particularly interesting. Merging RFID into ambient intelligence appears like a futuristic vision, especially in the context of hospitals. However, technological developments (Martínez-Pérez et al., 2012) are already advanced enough to envision smart hospital environments, where interactions and relations between assets, patients and clinical professionals could be seamlessly tracked, managed and monitored with RFID (Gomes et al., 2012). Such levels of connectivity and visibility will require the integration of complementary supporting information technology, raising the complexity of such undertakings.

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